

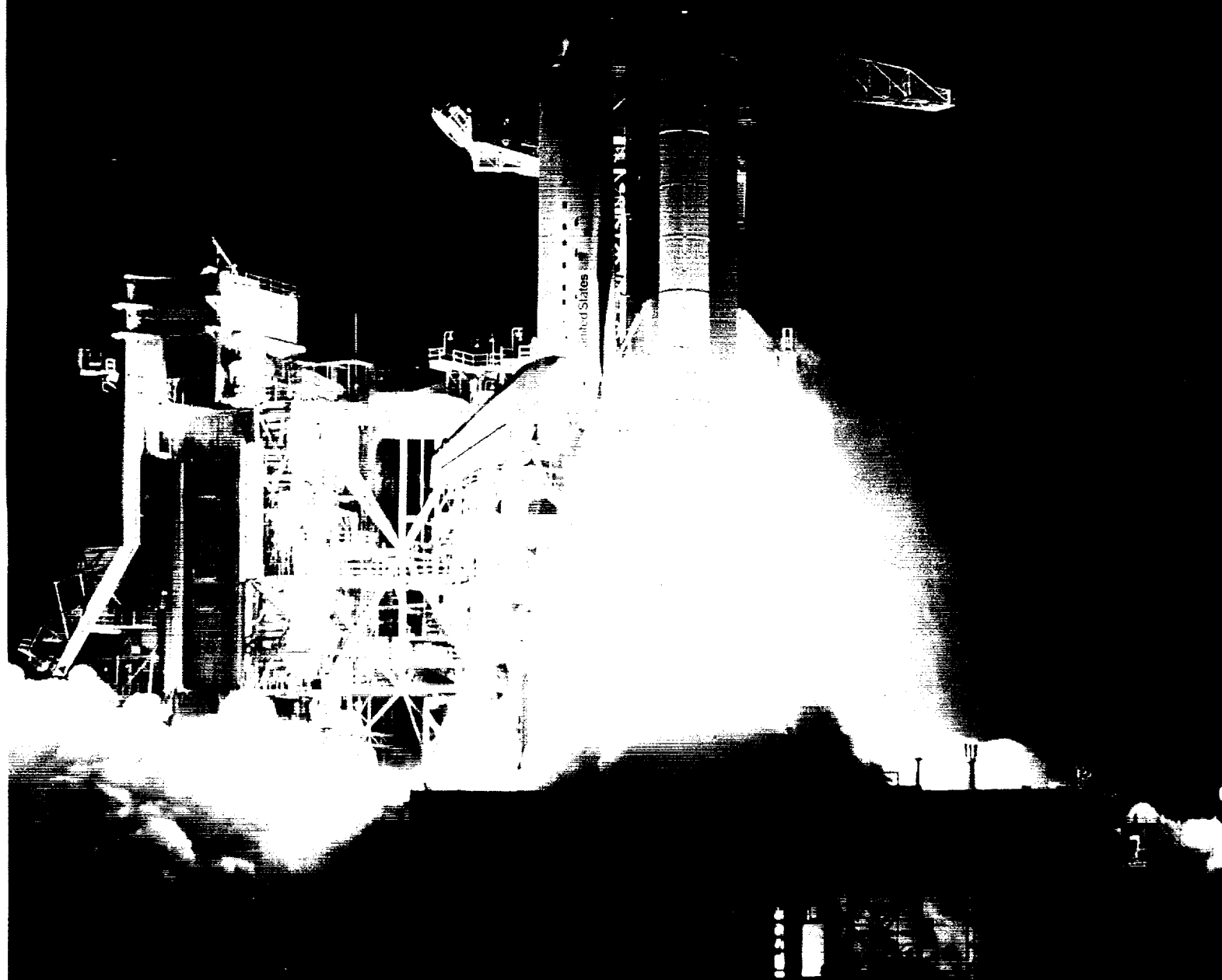
Life Sciences Report

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Prepared for the NASA Office of
Space Science and Applications
Life Sciences Division



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Foreword

Thirty years ago a small Soviet satellite was launched into Earth orbit. The world was astounded. Mankind had broken "the surly bonds of Earth" and had taken its first tentative step into the great unknown -- the final frontier of space. What an amazing series of accomplishments we have seen in space in the past 30 years! The "Space-Age generation" has witnessed the triumphs and failures of a fledgling space program -- the space race with the Russians to place satellites in orbit, sending humans into near space, exploring our solar system with robotic spacecraft, landing men on the moon safely and returning them to Earth, orbiting research stations used in conducting microgravity experiments and studies of our Earth, a fleet of Shuttles forming the core of an advanced Space Transportation System, and a permanently staffed and fully operational Soviet Space Station.

Our next generation in space promises to be no less astonishing or challenging -- or rewarding. As our U.S. Space Program matures, work at NASA continues to meet the challenges set forth in its charter. Ground-based research in support of space flight experimentation progresses in preparation for our return to the skies. The level of effort is increasing on the development of our Space Station. Among the challenges which lie ahead is the need to keep our human crews in space healthy and productive -- challenges in which NASA's Life Sciences Division plays a vital role to ensure the success of long-duration stays in space.

As part of the Office of Space Science and Applications, the Life Sciences Division directs one of the world's most extensive research programs on the effects of microgravity on living systems, sponsors development of advanced crew technology life support systems in Space Shuttle and on Space Station, and has the responsibility for medical operations supporting all human space flights. Life Sciences investigations have flown on several Shuttle flights and many experiments are scheduled for several near-term, dedicated missions on the Space Shuttle. Utilizing the Spacelab module secured in the Shuttle's bay,

researchers on the ground and the onboard mission/payload specialists work in unison to conduct experiments which may answer vital questions of scientific and practical value. There are also questions and concerns about crew health and productivity which must be addressed if a permanent human presence in space is to be a reality.

The Division also conducts a vigorous program to answer fundamental questions about the nature of life itself. The evolution of life, from elements to intelligence, encompasses many facets: the path by which life began on planet Earth, how life's evolution and development has been influenced by terrestrial as well as extraterrestrial factors, what global changes are occurring today and how they affect life on Earth, and the question of life, intelligent or otherwise, elsewhere in the Universe. The study of life in the Universe is a unifying theme within NASA, utilizing the Great Observatories to search our cosmic neighborhood for signs of life, exploring our solar system with robotic probes, and observing our own planet from on high as an incubator of life. The commonalities and the differences between our world and others are studied for clues that may aid in answering age-old questions.

Our own evolution into space is a profound step, not only in the human capability of expanding our boundaries but also as a direct confrontation of our evolutionary foundation on Earth. The breaking of this intimate relationship between Earth's gravity and life offers scientists a profound new perspective from which to study evolution in action. The Division's broad scope of biological investigations, involving humans, animals, plants, and cells, encompasses virtually all aspects of life sciences research in space. This undertaking requires an international cadre of investigators from many disciplines working in the common pursuit of knowledge which can only be gained through experiments performed in the microgravity environs of space.

Life sciences researchers from NASA, industry, and academia the world over have played active roles in the exploration of space

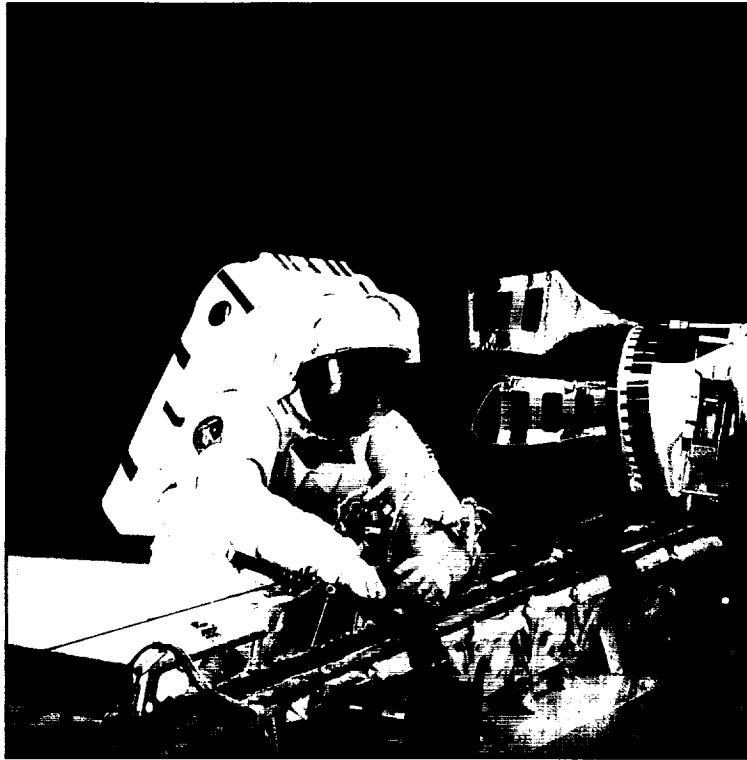
over the last three decades. Through the years, the Life Sciences Division has evolved and grown to meet the ever-increasing challenges and opportunities of our maturing space program. What has emerged is an extraordinary program of inquiry into the nature of life -- its origins, evolution, distribution and destiny. With a firm foundation of established research and building on the multidisciplinary

strengths through the newly-developed Life Sciences Strategic Plan, the Division is poised to make major and important contributions in the coming years.

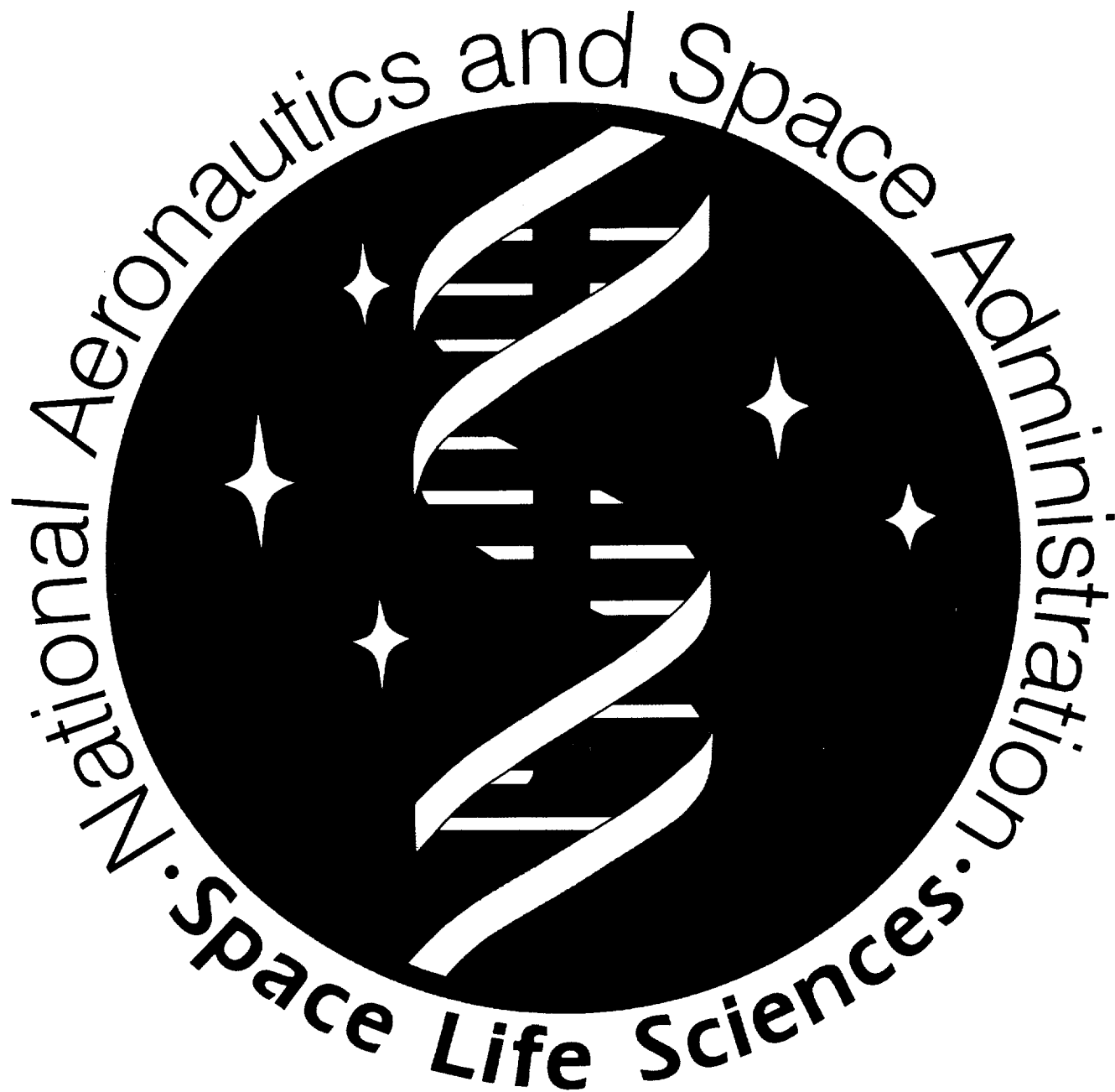
This report highlights the major research efforts of the Life Sciences Division in the past year and reviews the Division's preparation for playing a major role in our Nation's ambitious and vital quest in space.



Lennard A. Fisk
Associate Administrator
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Introduction

Life on Earth is distinguished by its great versatility and its ability to adapt. Living organisms thrive in the most hostile of environments, from the cold, dry valleys of Antarctica to dark thermal vents deep in the ocean. Even Apollo astronauts exploring the Moon discovered life--bacteria that had traveled from Earth with a landing probe and survived two years on the lunar surface, withstanding radiation, vacuum and extremes of temperature. Throughout the eons life has evolved in response to a changing environment, and now is itself influencing the environment on a global scale.

If scientists have long known of life's tremendous adaptability, only now in the space age are they coming to appreciate its broader context. The exploration of space has provided a new perspective for interpreting life in all its many forms and circumstances. No longer is biology confined to one planetary surface: at least two species--humans and bacteria--have visited another world, and countless others, from chimpanzees to bean plants, have experienced short times in Earth orbit, free of the earth's gravity influence. There also is evidence to suggest that life could be widespread in the universe: the chemical ingredients necessary for life--organic compounds and their constituent elements--are present in interstellar space, far beyond our solar system.

NASA's Life Sciences Division takes this extraterrestrial perspective as it pursues three related missions: enabling human beings and other species to safely venture into space; protecting the fragile biosphere of Earth; and exploring the universe for evidence of life forms that may exist on other planets.

Enabling astronauts to travel beyond their home planet requires the combined efforts of biologists, physicians and biomedical engineers, who study the adaptation of living organisms to space and who design the life support equipment and technologies that protect humans from its harmful effects. Plant physiologists and agronomists work on self-contained agricultural systems for long space voyages. Biomedical researchers seek countermeasures for space sickness and design the Space Station's health care facilities. Scientists and engineers from many disciplines work to keep humans healthy in space.

Photographs of the Earth taken from space, along with satellite data, have contributed to a new awareness of our planet as an integrated, interdependent biogeochemical network, where oceans, atmosphere, land and living organisms affect each other in subtle and complex ways. The Life Sciences Division contributes to NASA's comprehensive "Mission to Planet Earth" initiative by detailing the biological component of this global system--how, for example, deforestation and other human

practices may be threatening delicate ecological balances. The aim of this space- and ground-based research is to help protect life on planet Earth as it exists today.

Finally, the Life Sciences Division seeks to explore the limits of the biosphere. Is life confined to Earth, or have similar conditions that led to its existence and evolution here been duplicated many times over throughout the many galaxies of the universe? These "exobiological" studies extend from basic investigations of the chemical composition of interstellar dust to active searches for evidence of intelligent extraterrestrial life.

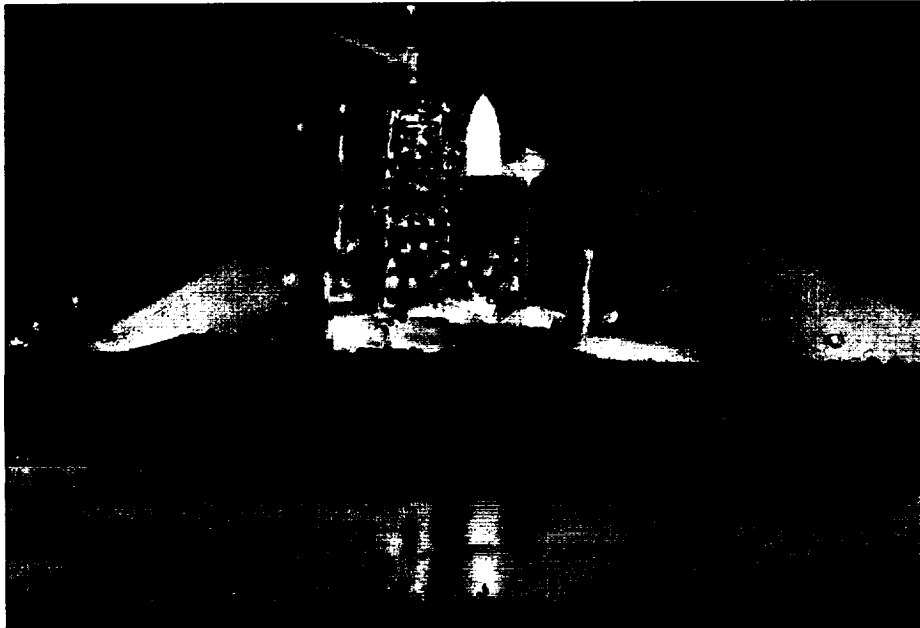
Accomplishing this threefold mission--to enable, protect and explore--requires the close cooperation of the many disciplines within the Life Sciences Division: Space Medicine and

Biology, which includes traditional biomedical research, space human factors, and operational medicine. Biological Systems, which includes Biospherics, Controlled Ecological Life Support System (CELSS) research and Exobiology; and Flight Programs, which implements inflight experiments complementing ground-based research at NASA research centers, universities around the country, and scientists from the international community.

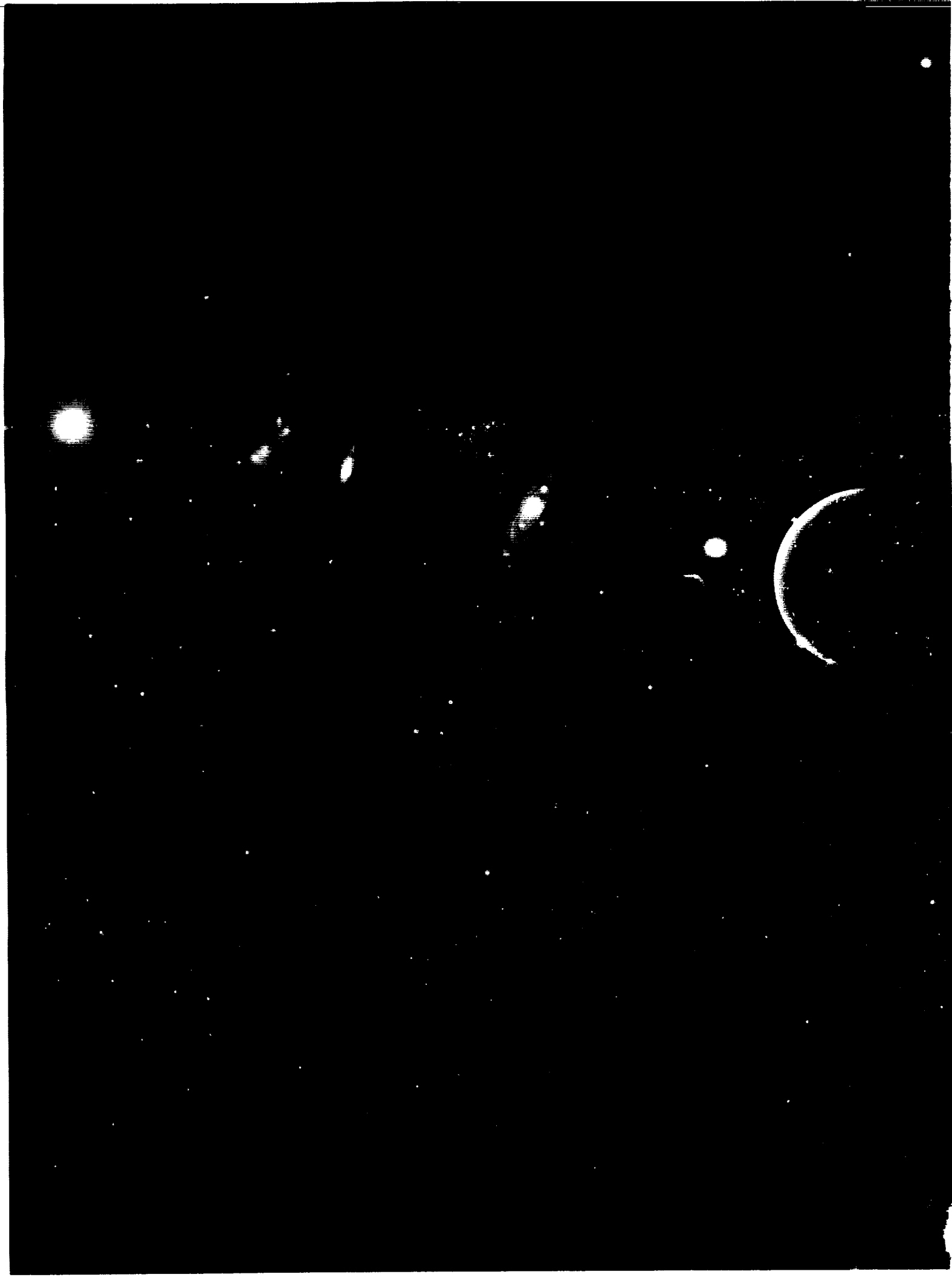
With a combination of basic and applied scientific research, the Life Sciences Division ensures the health and well-being of human crews in space. At the same time, it addresses some of the most fundamental questions of mankind: How did life arise on Earth? How is it changing? Does it exist elsewhere in the Universe?



Arnauld E. Nicogossian, M.D.
Director
Life Sciences Division
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Life Sciences In Space: The Quest for Answers

Life had its origins in the cosmic burst of matter and energy that marked the beginning of the universe itself--the Big Bang. The story of evolution continues with atoms created uncountable millennia ago in the nuclear furnaces of stars now long dead. Certain chemical elements upon which life would eventually depend were formed and coalesced into organic molecules that became the precursors of life. Once formed, these molecules interacted with each other and their environment, changing molecular structure and becoming increasingly complex as time passed, until a precise combination of molecules produced the most fascinating phenomenon in the universe--life. Once life began, it continued to evolve in a dynamic relationship with its environment, eventually emerging from simple one-celled organisms to creatures sufficiently complex to support the elusive quality of intelligence. As intelligent life on Earth flourished and became human, we began to ask the questions: What is the nature of life? How did it begin? How is it evolving? What is its relationship with its environment? What will be its eventual fate? Has it happened elsewhere?

The search for answers to these questions encompasses more than 2000 years of inquiry and has produced the sciences of physiology,

medicine and biology. In developing the tools and concepts needed to address such questions effectively, the life sciences have become linked with the sciences of physics, chemistry, geology, engineering and astronomy. Now, using these tools, we are leaving our home planet to reach outward for answers. We have begun to search the universe for life beyond Earth and for other intelligent species. We are gaining new knowledge of our own human function and our capacity to live and work in space. As we journey into space, we are bringing other organisms from Earth with us to explore fundamental questions about gravity's role in the formation, evolution, maintenance and aging processes of life on Earth. From the vantage point of space, we are examining our home planet in relation to the solar systems it inhabits and seeing it as a unit, unique among its planetary sisters. From this global perspective, we have begun to synthesize and integrate the dynamic interactions between life and its environment into a cohesive concept. Many of these studies are leading us to ask some very practical questions about the habitability of our own, and other, solar systems, as we lay the foundation for a new home beyond the familiar confines of our world.

The theme of the Life Sciences Program is a systems perspective of life's relationship to its environment. The ideas that there is an underlying unit encompassing all phenomena of life, and that the origin and evolution of life are woven into the evolution of the planet itself, are relatively recent developments. They are ideas in whose development NASA has played, and will continue to play, a critical role.

The organizational structure of the Life Sciences Division (shown below) encompasses exploration of the relationship of life and its environment on four scales:

The Exobiology Program examines the origin and evolution of a living planet in relation to the evolving universe.

The Biospherics Research Program investigates the interaction between living and nonliving components of Earth on a planetary scale to understand how these components influence each other.

The Gravitational Biology Program examines life's relationship with gravity on the scale of individual organisms through ground and flight studies.

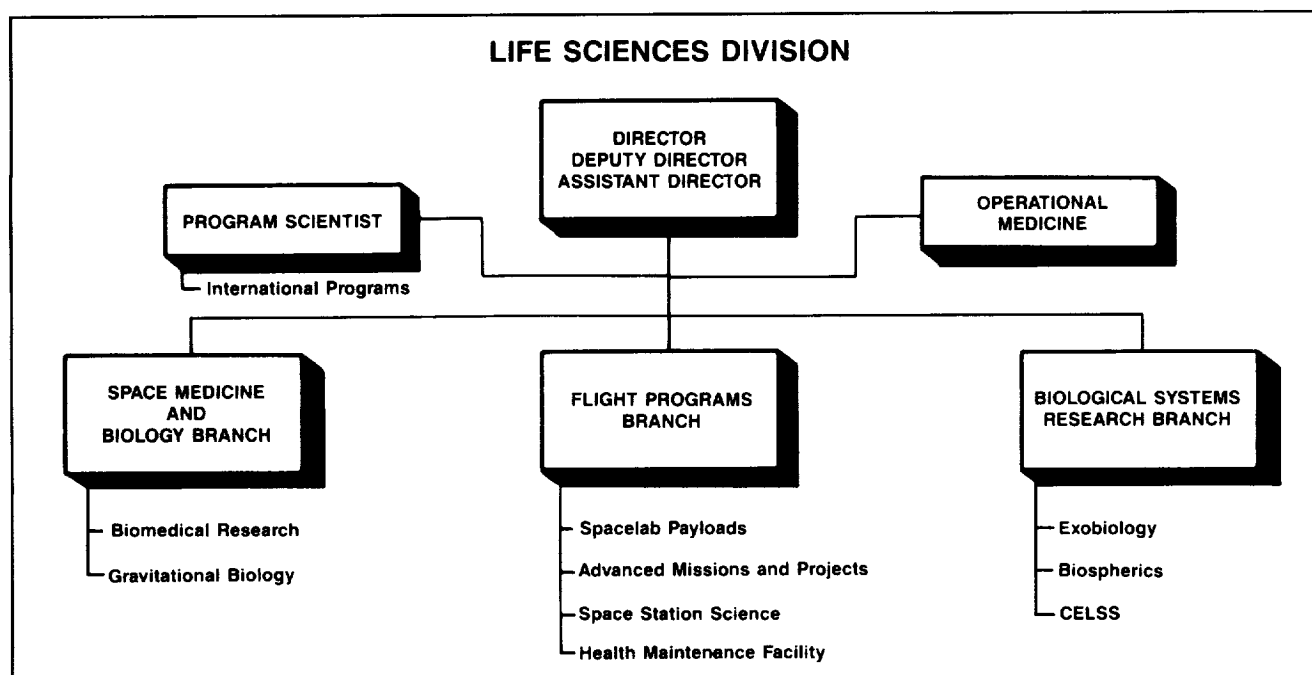
The Biomedical Research and Operational Medicine Programs examine the influence of the space environment on human health, safety, well-being and productivity.

The Division's Controlled Ecological Life Support System (CELSS) Program blends the

biomedical, gravitational biology, biospherics and engineering expertise of the Division to develop the support systems for spacecraft that can process wastes and regenerate food, air and water. Such systems are needed for long-duration manned missions such as solar system explorations or manned bases on other planets, where resupply of vital materials from Earth is impractical or impossible.

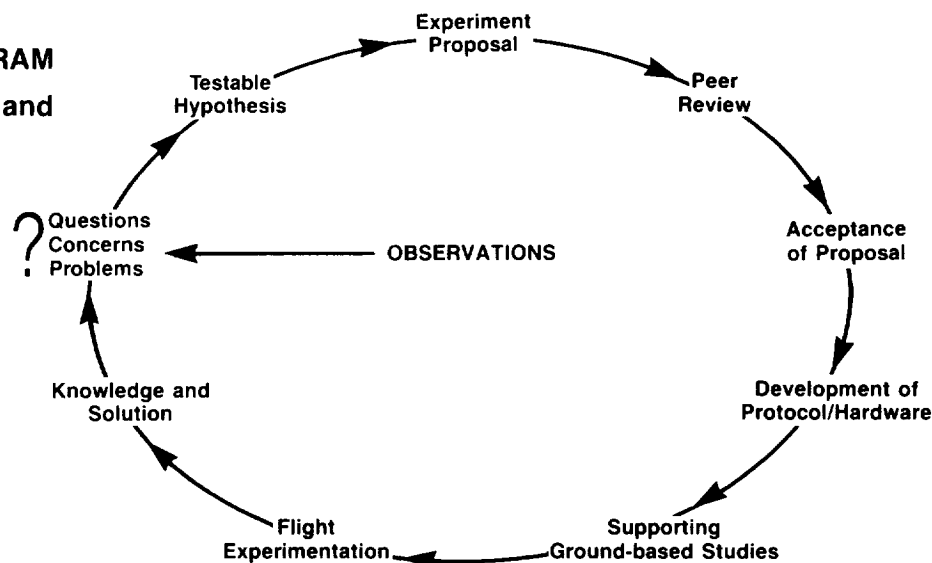
Each program described above requires access to space for research. Special laboratory equipment and experimental procedures must be specifically designed for use in space. In addition, flight experiments must fit within physical limits of the spacecraft and must allow as many experiments as possible to be conducted on each mission to achieve maximum scientific return. For these reasons, the design of successful flight experiments requires a unique interaction between research scientists and flight engineers.

The Flight Programs Branch is responsible for developing equipment, facilities, expertise, and flight opportunities needed to assure successful conduct of investigations in space. In addition, the Flight Program works to transfer knowledge gained from spaceflight into a form accessible and usable to the research community at large, and to develop new technologies and equipment for future flight and ground-based applications.



LIFE SCIENCES RESEARCH PROGRAM

Steps of Research and Development



In recent years, life sciences investigations have been conducted onboard the space shuttle. In some cases, results of these investigations have confirmed classical or generally held hypotheses. However, other results have been startling and unexpected, requiring researchers to reexamine their assumptions about the intricate relationship between gravity and life.

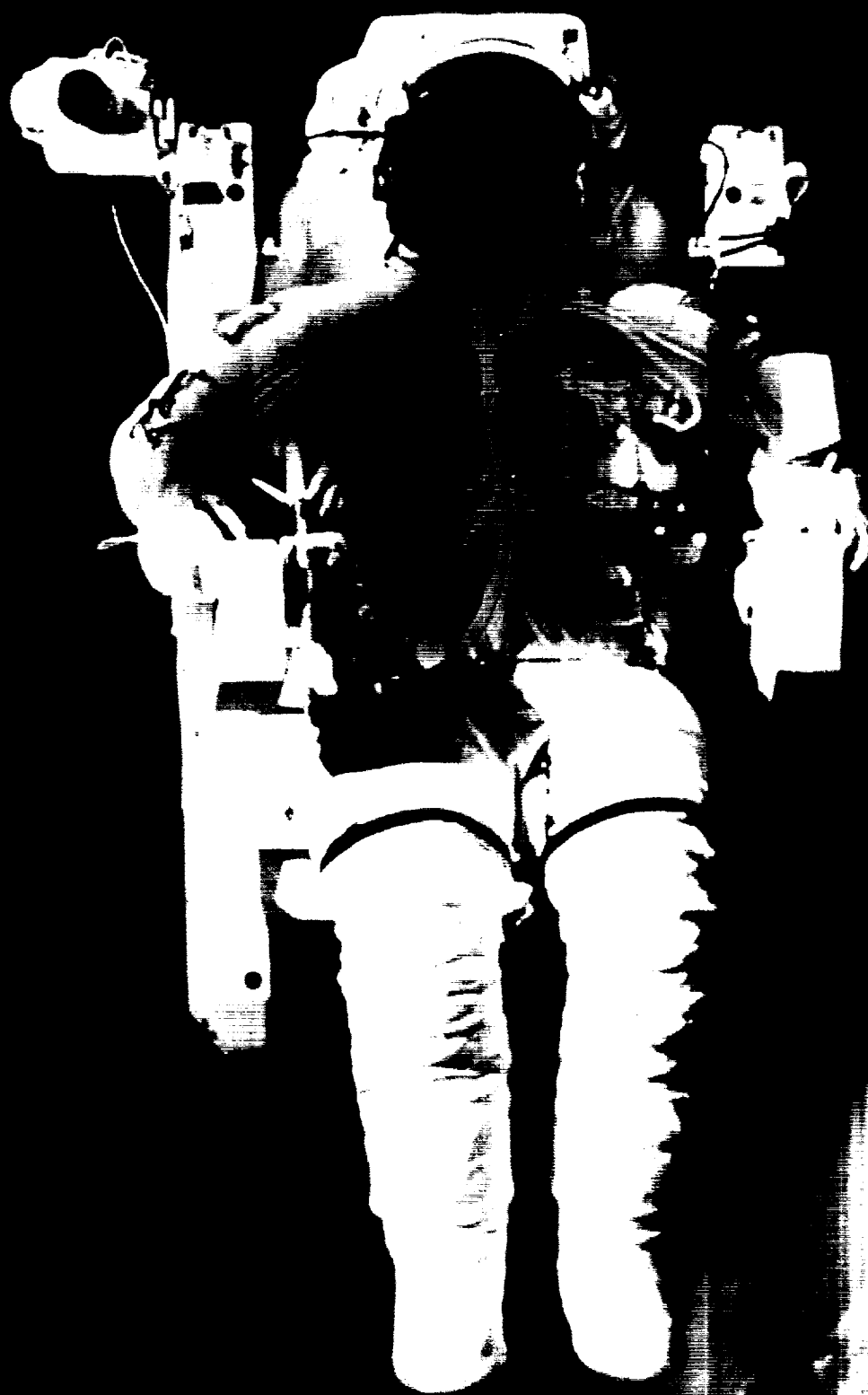
The Life Sciences Research Program flows in a progression (figure above), beginning with challenging problems and questions crucial to our advancement into space; the search for solutions and answers through research in the biological and medical areas; validation and demonstration of crucial concepts in flight which eventually lead to the knowledge, experiments, and progress which will enable us to meet the challenges of the future.

NASA centers and the research community contribute in various ways to the Life Sciences Program. The work is done by NASA scientists, guest investigators and contractors, and ranges in its nature from basic to applied research. The in-house program amounts to about 40 percent of the Life Sciences budget. The remainder of the research is undertaken by university, research institute and industrial scientists. Both in-house and extramural research is peer-reviewed by panels of scientists selected and convened by such organizations as the American Institute of Biological Sciences (AIBS)

or the Federation of American Societies for Experimental Biology (FASEB). These organizations also review specialized studies within specific areas of research. Each research proposal is evaluated and assigned a numerical rating for scientific excellence. Relevance to NASA objectives is another important criterion. Based on these two parameters, NASA officials select research for funding.

All ongoing research is reviewed annually. This process of rigorous and continuous appraisal has produced a stable and productive program of basic and applied research in the life sciences.

During this new era of space exploration, we are crossing the threshold of space to confront the universe with questions. We are now in the technological and intellectual position to effectively search for answers that will enable us to move forward into this "new frontier." The following chapters will examine the implications of NASA life sciences research: what we know, what we have accomplished this past year, what this means to our future in space, and what remains to be learned if space is to become a permanent part of the human domain. We will examine how the NASA Life Sciences Division uses the space environment to answer questions about life, and how it works to protect the health and well-being of space travelers, now and in the future.



Operational Medicine: Remote Health Care Delivery

One of the primary missions of the Life Sciences Division is to ensure the health of crews working onboard spacecraft and in the hostile environment outside their vehicles. Enabling humans to live in space and return to Earth in good health requires the use of technologies such as spacesuits, pressurized living quarters and radiation protection, as well as new operational procedures adapted to the peculiarities of microgravity.

The responsibilities of the Operational Medicine Office of the Life Sciences Division range from screening new astronaut candidates to establishing procedures for emergency medical care in space. Medical matters of flight safety and health come under its purview, as well as ground procedures that have an impact on crew safety.

The latter responsibility includes training crews and medical support personnel for rapid emergency response should an accident occur on the launch pad. In the past year, simulations were conducted at the space shuttle launch site to verify triage operations and other procedures to be used in the event of emergencies.

Because many of the clinical techniques commonly used on Earth are inappropriate or not feasible in space, physicians and engineers in the Life Sciences Division continue to explore alternative techniques for obtaining vital physiologic measurements during a spaceflight. Non-invasive devices are being designed to monitor biomedical data remotely via close-range telemetry, thus eliminating the need and inconvenience of traditional hard-wire techniques.

The Operational Medicine Office adapts existing medical technologies and procedures for use onboard spacecraft or develops new ones in order to perform its mission of maintaining the health of space crews traveling to Earth orbit and beyond.

Earthly Benefits From Space Research

Solving the problem of providing emergency cardiac care during spaceflight may lead to new devices that could improve life-saving techniques on Earth.

Under normal conditions, cardiopulmonary resuscitation (CPR) involves repeated applications of force to the patient's chest while ventilating the lungs. In space, however, both patient and rescuer are floating free. Unable to stabilize the patient on a surface and with no force of gravity to provide weight, the rescuer could not easily perform Earth-bound CPR.

This problem has been bypassed by innovative modification of the conventional technique. The patient is secured on a table-like restraint, and the rescuer is held in place over the patient with a simple harness attached to the restraint. The harness prevents the recoil force of the chest compressions from propelling the rescuer away from the patient, and conventional CPR can be effected.

Another method utilizes a lever-arm device, which attaches to the side of the patient restraint. A smoothed rectangular block, attached with a swivel joint at one arm of the lever, is placed on the patient's sternum. The force for the chest compressions is applied by the rescuer using the handle at the other end of the lever. Providing chest compressions for CPR in this manner is nearly effortless. Both methods have been tested successfully in simulated weightlessness onboard KC-135 aircraft using CPR manikins.

In addition, NASA researchers are testing advanced cardiac life support techniques, including a pneumatic vest that could be inflated quickly to provide a sharp increase in thoracic pressure automatically. Initial trials of the pneumatic vest have shown promise. If its safety can be demonstrated for humans, the device could be incorporated into an emergency medical package for use in space, and could lead to improved CPR techniques on Earth.

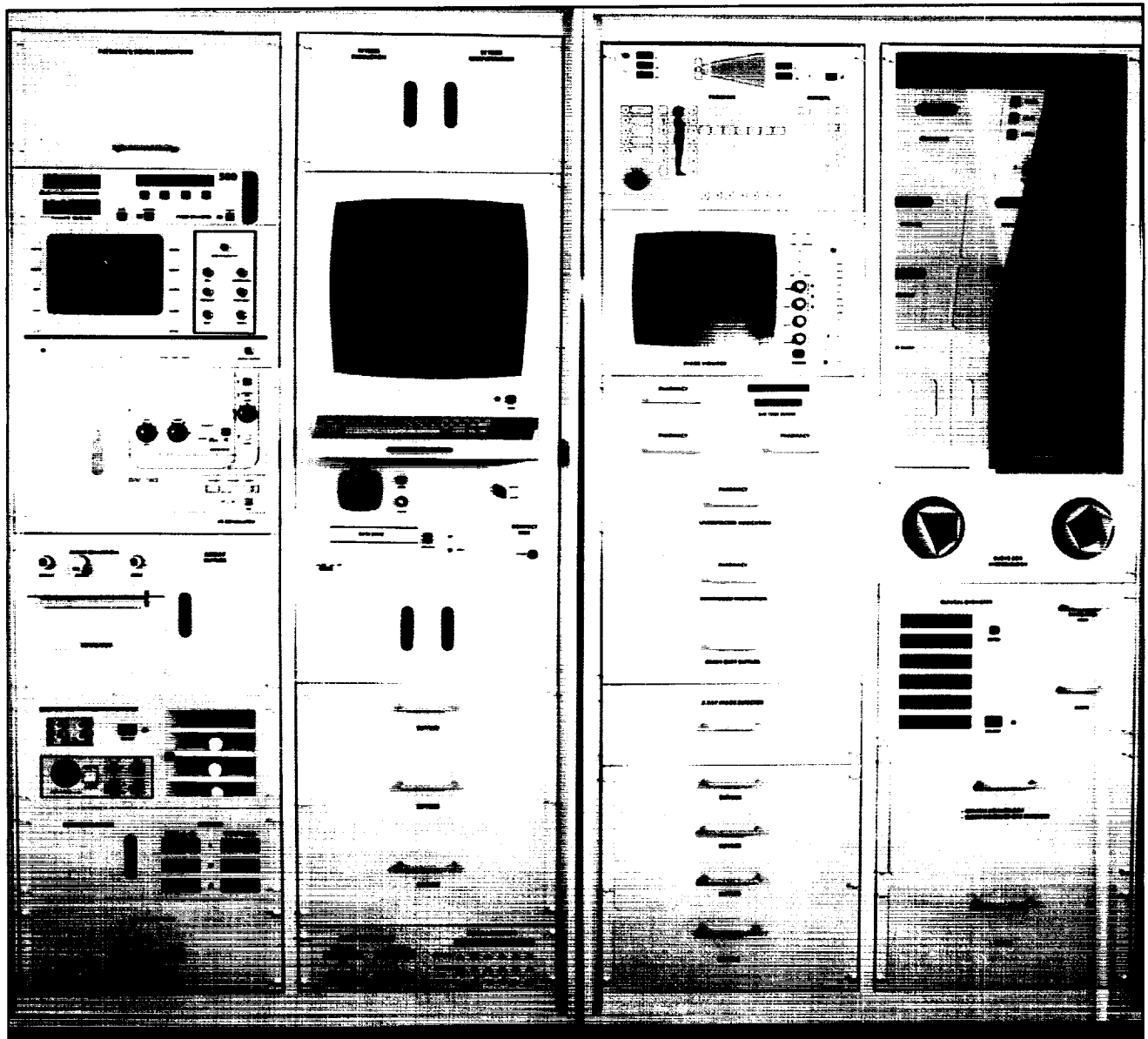
Health Maintenance Facility

The U.S./international Space Station of the 1990s will be a permanent base in Earth orbit where six to eight people will live for six months at a time, or longer, during a typical tour of duty. The medical requirements for the Space Station will be greater than for the shuttle, due to the Station's size and complexity, habitability requirements, longer crew stay time and other factors.

While the Station will be equipped with a rescue vehicle that could bring a disabled crew member back to Earth in an extreme emergency, an onboard "clinic" will be

necessary to stabilize a patient before a rescue can be attempted. This clinic, the Health Maintenance Facility (HMF), will provide preventive medical, diagnostic and therapeutic capabilities.

The HMF is now advancing from concept to hardware design. Like other facilities on the Space Station, it will occupy racks fixed to the walls of the pressurized cylinders that are the Station's working and living quarters. It will include basic equipment for emergency life support, exercise programs, intravenous fluid therapy, diagnostic imaging, general and dental



The Health Maintenance Facility designed for Space Station.

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surgery, as well as a pharmacy, clinical laboratory facilities, monitoring instrumentation and computerized diagnostic aids for medical personnel onboard the Station.

A key component of the facility will be its computer system, which will integrate data from the various onboard medical instruments, assist in diagnoses and maintain a complete medical record of the crew--a complex job for which no computer system currently exists. A prototype of the hardware for this Medical Information Bus has been built, and preliminary software has been developed. The software is based on existing medical diagnostic programs, with modifications made for the HMF. The final result will be a program that can integrate and display laboratory test results and diagnostic data on a single computer screen. Physicians on the ground will also have access to the system, which could eventually become a standard for the medical industry on Earth.

Instead of conventional X-ray films, the HMF will use digital radiographic imaging that can be "down-linked" to doctors on the ground. Commercial units are being surveyed for possible modification for the HMF. The facility also includes a system for preparing and delivering intravenous fluids. Unlike the familiar hospital intravenous drip system, this delivery system must function in the absence of gravity, and must be able to separate gas and liquid phases. A pump for the system has been developed and tested onboard a KC-135 aircraft that provides brief periods of weightlessness during parabolic flight. An ultra-filter able to provide sterilized Space Station water for medical use also was developed recently for the microgravity intravenous infusion system.

The Health Maintenance Facility will be located in one of the Station's four habitable modules, but a medical emergency might happen anywhere onboard. The crew will therefore need a medical life support system, equivalent to a hospital "crash cart," that could be used to stabilize and transport an injured or ill crew member from other parts of the Station to the HMF, or to a rescue vehicle in the event of an accident. Such a system would include ventilator and intravenous fluid subsystems, as well as equipment for resuscitating and monitoring the patient. The HMF designers are

now evaluating and selecting hardware that could be modified for use on the Station. Similarly, a patient restraint device is being fabricated that will serve as a hospital bed, a transport litter, and a dental chair.

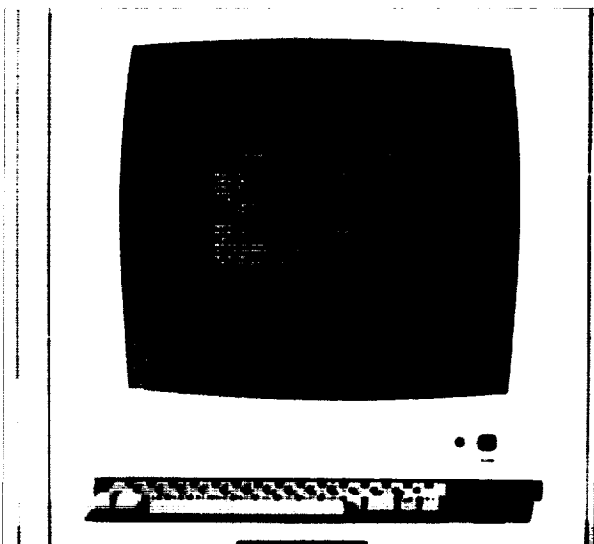
Earthly Benefits From Space Research

Physicians facing difficult diagnostic problems often consult medical reference books and current journals for the most recent information available. On the Space Station, however, "shelf space" will be limited, and essential data will be in computerized rather than book form.

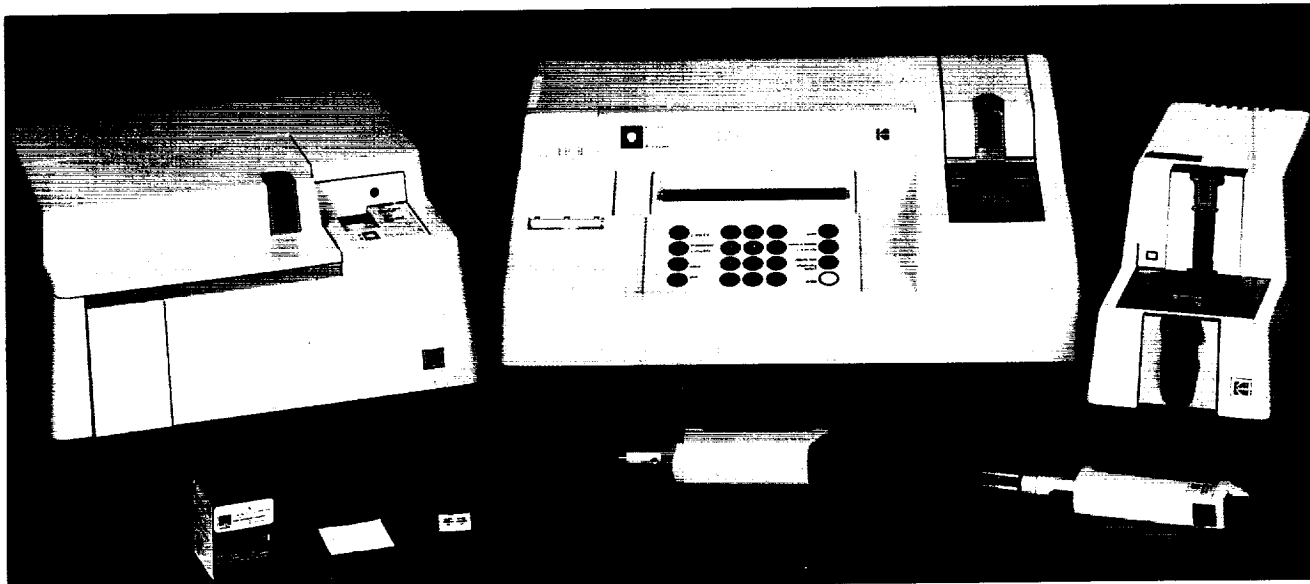
With that in mind, researchers at the Johnson Space Center are developing a medical operations data base for use on the Space Station. Researchers at the University of Florida, under contract to NASA, also are developing a microcomputer-based medical decision support system that can present a small library of essential medical knowledge to medical personnel on the Space Station.

Standard medical references, including graphs, pictures and illustrations, already have been entered into a prototype decision support system. The final system will use artificial intelligence techniques to recognize key words and patterns while searching through tens of thousands of medical documents.

Aside from its use in space, such a computerized medical library could ultimately be put on laser disks and be made available to physicians in any office with a personal computer.



Computer access and display console for the Health Maintenance Facility.



A clinical laboratory sub-system for the Space Station. Evolving, in part, from technologies developed during earlier space research, currently available, off-the-shelf analytical systems have been identified for use in the Health Maintenance Facility. Diagnostic sub-systems for microbiology, hematology, urinalysis, and clinical chemistry are being evaluated and modified for inclusion in the HMF.

Extravehicular activity, or EVA, is another activity that must be carefully planned and monitored to ensure crew health. Like underwater divers re-surfacing from great depths, crew members leaving the safety of the Space Station for a suited spacewalk must be careful when going through decompression procedures to avoid sudden drops in atmospheric pressure that could cause the "bends" --a painful bubbling of nitrogen in tissue and blood. Medical personnel therefore are making plans for this type of medical emergency. An emergency treatment protocol has been established whereby the pressure in a sealed airlock would be quickly raised from the six pounds per square inch (less than half the normal Station pressure) required for EVA to normal pressure and a 21 percent oxygen atmosphere. This hyperbaric treatment with an oxygen-rich atmosphere might also be of value in the event of blood loss or burns, as it forces additional oxygen to hypoxemic tissues.

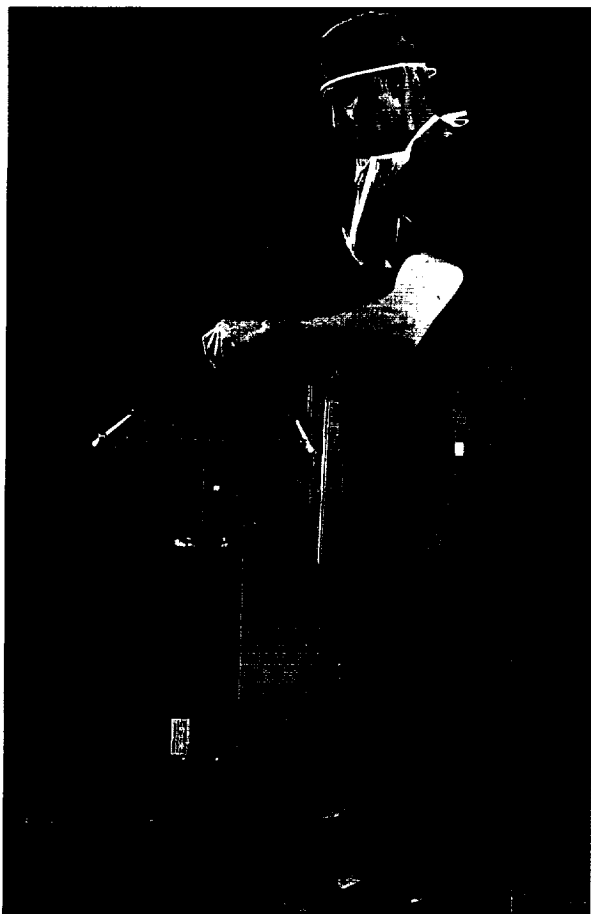
A clinical laboratory system for body fluid chemistry analysis, microbiology workups and other routine tests was also chosen recently for

the HMF, as were drugs for the onboard pharmacy.

The HMF is the most sophisticated medical facility yet designed for a spacecraft. As the Space Station evolves in the 1990s and beyond, so will the HMF continue to be refined and improved to provide state-of-the-art health care for space crews in orbit.



Living and working safely in space. Astronaut Bruce McCandless II tests the "cherry picker" during this extravehicular activity (EVA) of Mission 41-B, February 7, 1984.



The Microgravity surgical workstation will provide a stable operating surface upon which minor surgery can be performed. Essential components of the support frame and medic/surgeon retention system are shown.



Components of a generic workstation are tested during simulated weightless conditions onboard a KC-135 research aircraft. During the parabolic arc maneuvers, tests were conducted on a medical suction/air-fluid separator unit, a volumetric intravenous fluid infusion pump and in suturing synthetic skin incisions.

An Operating Room in Orbit

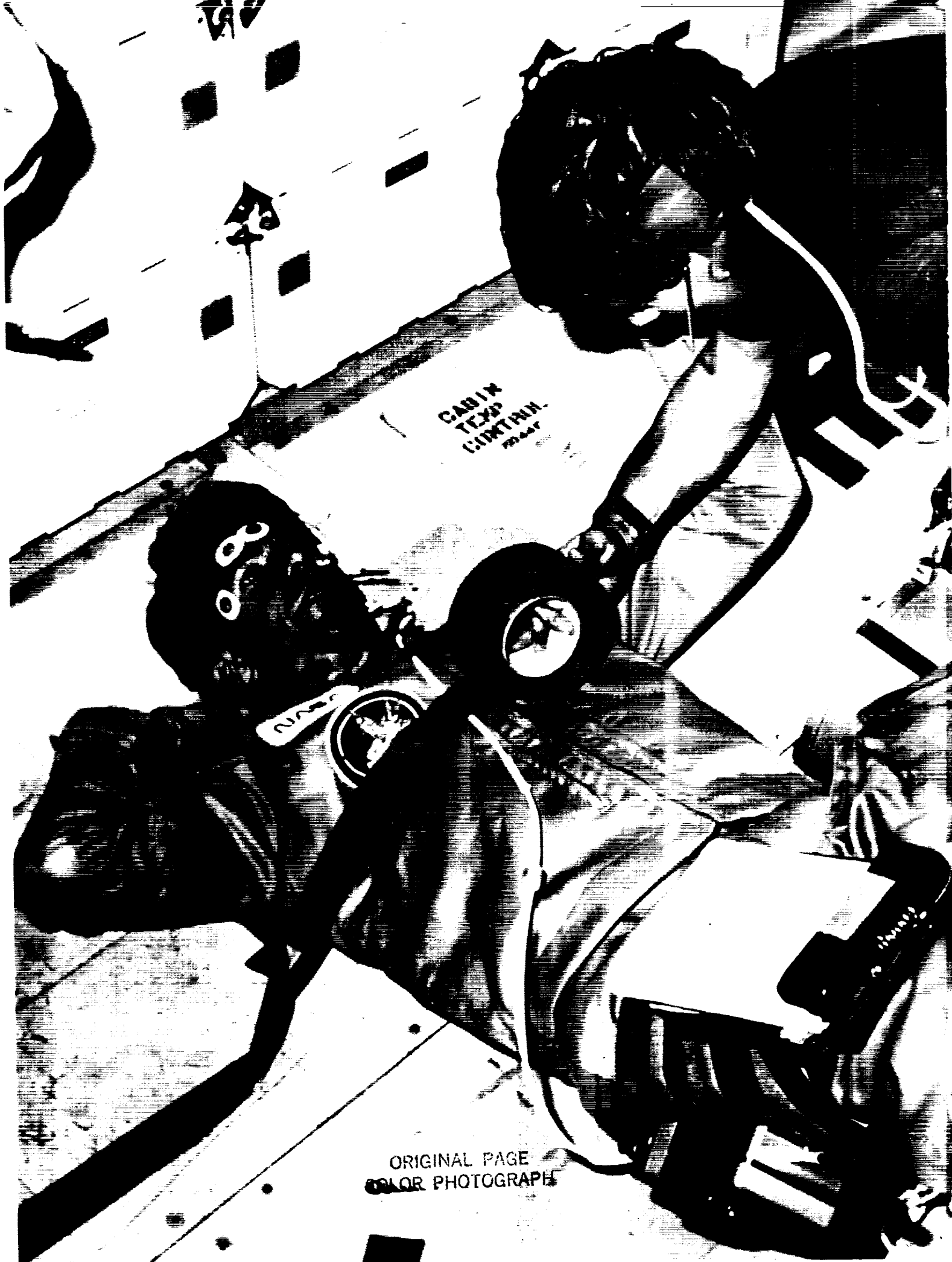
Because the Space Station will be a permanently occupied, complex facility, medical emergencies may occur onboard that will require the crew to perform minor medical, surgical or dental operations without direct help from flight surgeons on Earth.

These might include such minor procedures as suturing, extracting teeth or draining abscesses. Medical personnel on the Station may need to administer anesthesia or drain fluids with suction devices, all while they and the patient are in the microgravity environment.

To support these kinds of operations, a modular microgravity surgical work station has been designed at the University of Texas Health

Science Center at Houston, and a prototype has been built and tested during brief periods of weightlessness onboard a NASA aircraft. The anchored work station has toe catches and a belt restraint to hold the floating operator in place, and there is a support surface/cradle for the patient that doubles as a transport litter. Instrument trays fixed to the work station are magnetized to hold steel surgical instruments. Parabolic flight tests of the attached suction pump system have shown that it is possible to transfer several liters of fluid with minimal accumulation of air.

All work to date suggests that it will be possible to perform minor surgery in space with only a few modifications to equipment and techniques used on Earth.



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Space Biomedical Research

Space is a new environment for mankind. Human beings have been able to travel beyond the Earth for only a single generation, and most of what is known about the body's adaptation to spaceflight has been gathered from a few long-duration missions flown over the past three decades. What is known may give cause for concern: muscles atrophy in space, bones lose mass and minerals, red blood cell counts drop and body fluids shift headward in the absence of gravity's influence. After long stays in orbit, space crews show a decreased orthostatic tolerance--their ability to stand upright without fainting is impaired temporarily when they return to Earth.

NASA has moved from an era when only a few highly trained test pilots flew short space missions to a time when many people of various backgrounds will be living and working on orbiting space stations, lunar bases and vehicles bound for other planets. Unless fundamental questions about the human body's adaptation to spaceflight are answered, these long-duration missions may not be possible.

Tours of duty on the Space Station are planned to extend up to half a year. A round-trip journey to Mars using current propulsion technology would take about two to three years. During this mission the crew would be entirely free of gravity's influence, except for a short time on the surface of Mars, when they would have to adjust to a gravitational force 38 percent as strong as Earth's. Traveling to a lunar base would require only a few days in weightlessness, but living on the Moon's surface would mean adapting to one-sixth of Earth gravity for long periods. Also, readapting to Earth gravity after a lunar stay would have physiological effects.

These new challenges make studying gravity's influence on human physiology of paramount importance. One proposed solution

to alleviate the problems of weightlessness is to have a vehicle that could rotate, thus providing artificial gravity. Not only does this present a tremendous engineering challenge, but life scientists must also learn how animals and humans react to Coriolis forces (inertial forces caused by rotation) and other unique characteristics of rotating environments. Preliminary work using small centrifuges and experimental rotating rooms is being conducted in this area--one of the many space biomedical research programs aimed at understanding the human organism's reaction to the new environment of space.

Environmental Health

A spacecraft is a self-contained environment where the air composition, pressure, humidity, and temperature are maintained and controlled. Air must be circulated continuously to remove exhaled carbon dioxide that would otherwise concentrate around a person's head in the absence of convection in microgravity. Airborne particulates and pollutants are "scrubbed" from the cabin air continuously. The "out-gassing" of vapors and potentially toxic gases from plastics, paints, glues and other common materials in microgravity must also be addressed.

Precise environmental control has long been an important part of the manned spaceflight program. Whereas industrial health and safety standards on Earth are based on an eight-hour work shift, crews in space are exposed to their work environment continuously. Spacecraft environmental engineers are now establishing air and water quality standards for long-duration missions on the Space Station. Setting protocols for pressure changes that will be required for frequent spacewalks and establishing safe treatment procedures for decompression sickness are included as environmental factors.

Astronauts Joseph P. Allen, IV (right) and William B. Lenoir conducted biomedical investigations in the mid-deck of the Earth-orbiting Space Shuttle "Columbia" on Mission STS-5.

Unlike previous U.S. spacecraft, the Space Station will recycle all waste water produced by crew members and onboard processes for re-use as potable water. Acceptable water quality levels must therefore be defined, and biomedical engineers are now evaluating equipment for monitoring the bacteriological and chemical quality of the Station's water supply.

Onboard air quality is also maintained. Preliminary maximum allowable concentration limits for a list of potential atmospheric contaminants have been established for 120-day missions. Acceptability limits for the size of airborne particulates have been set for the Space Station. Studies are presently being conducted to characterize all potential sources of contaminants and toxic substances. Once determined, methods to mitigate or remove these airborne contaminants will be pursued.



Perhaps the greatest threat to life in space is the radiation that streams continually from the Sun or enters our solar system in the form of galactic cosmic particles. Crews in low Earth orbit of modest inclinations are somewhat sheltered from this hazard by the Earth's magnetosphere. However, orbits of high inclination or high altitude no longer provide this protection. High doses of radiation in space, such as those produced by a solar flare, may have deleterious effects on an unprotected crew ranging from nausea and disorientation to complete incapacitation or even death.

Life scientists therefore are assessing the risks of radiation to spaceflight crews and searching for physical or chemical countermeasures and methods of protection. Much of the work to date centers on quantifying the relative biological effects of the different types of ionizing radiation. The mass, energy and path of an ion or uncharged particle determine its ability to penetrate matter or cause damage to living cells. Very energetic heavy ions called HZE particles, for example, can easily break chains of DNA in the cell nucleus or cause other similar cellular damage. Biotechnology researchers at the Jet Propulsion Laboratory in Pasadena, California use tiny nematodes--a type of roundworm--as a model animal to study the genetic effects due to heavy ion radiation damage. Nematodes are excellent biological subjects for this research, as their DNA structure is well-known and genetic mutations can be detected easily. This biodosimeter gives information on the genetic damage caused by a particle whose character, energy level and path can be determined.

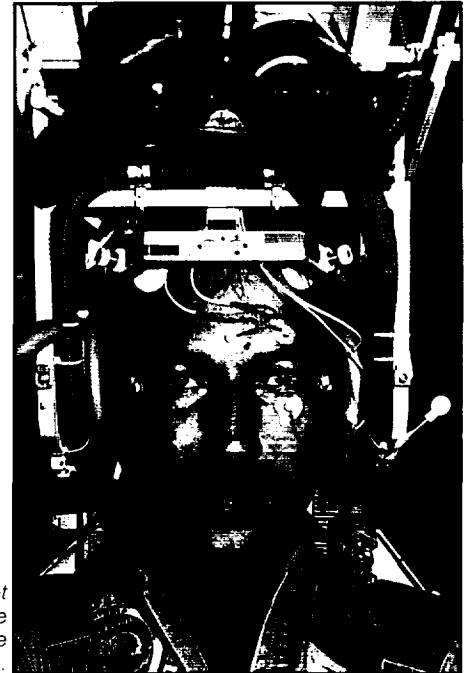
In collaboration with the Lawrence Berkeley Laboratory in California, the Bevatron particle accelerator is being used to study the effects of heavy ions (up to iron-58 in atomic mass) on biological tissues and shielding materials. These experiments will assist in establishing biological dose levels as a function of shield type and thickness. Different metals and composite materials are also being evaluated for their

Astronauts Edward G. Gibson and Gerald P. Carr are shown in the forward experiment area demonstrating zero-g effects on weights. The ability to "lift" a person with one finger dramatizes the unloading effect in microgravity on weights, muscles, and bones. Three Skylab 4 crewmen lived in the weightless environment for a total of 84 days.

ORIGINAL PAGE
COLOR PHOTOGRAPH



Payload Specialist Charlie Walker collects a saliva sample during STS Mission 61-B as part of a pharmacodynamics study.



Mission Specialist Wubbo Ockels wears a helmet designed for vestibular studies. Electrodes detect eye movements during linear acceleration experiments on the first German-sponsored Spacelab mission, D-1.

effectiveness in shielding Space Station occupants from radiation.

Recently, the National Council on Radiation Protection completed a study to reevaluate career and annual organ radiation exposure limits set for spaceflight crews in 1970. As a result, these dosage limits (which take both age and sex into account) are more stringent for various types of exposure, in accordance with more recent radio-epidemiological data and the expectation that greater numbers of people will live and work routinely in space in coming decades.

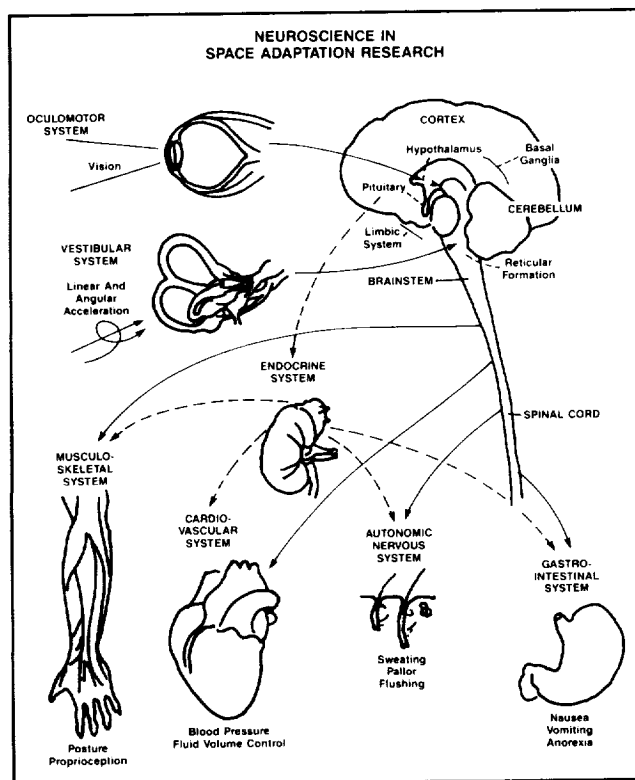
Space Physiology

Space Adaptation Syndrome

Half of all astronauts who spend time in orbit are subject to a form of motion sickness known as Space Adaptation Syndrome (SAS). This problem typically lasts for the first several days of weightlessness and includes symptoms from headaches and fatigue to nausea and vomiting. Consequences of this "space motion sickness" range from simple discomfort to possible incapacitation, creating potential problems during reentry and emergency egress from the spacecraft.

In weightlessness, the body receives a variety of conflicting neurosensory inputs from visual and tactile senses and from the balance organs of the inner ear. This conflict is thought to be the primary cause of SAS. However, the precise mechanisms of the conflict are not well understood, and a practical, effective therapy has yet to be developed. There is also evidence from space shuttle experiments that neurosensory changes take place continuously during spaceflight, and even after landing, long after the acute symptoms of motion sickness have subsided.

In their effort to understand the mechanisms responsible for SAS, researchers use a wide variety of testing equipment on the ground, such as rotating chairs and accelerating "sleds," and conduct tests onboard NASA aircraft that simulate weightlessness. Sixteen such test flights were conducted in 1986 alone. In addition, unique resources such as the Ames Research Center's Vestibular Research Facility (VRF) are used to study the effects of motion and gravitational stress. The VRF generates precise rotational and linear accelerations under controlled conditions, and records eye movements and electrophysiological signals in human surrogate test subjects used in vestibular research.



The goal of SAS research is to understand the complex mix of psychological, sensory and physical factors that cause the malady, and to find some countermeasure--a training program, medication or perhaps a combination of the two.

Although SAS is similar to motion sickness on Earth, physiological changes due to weightlessness may also be contributing factors. Researchers testing an experimental helmet to be worn by crewmembers during studies of neurosensory adaptation in space have found that the mass of the helmet could be a factor in the onset of motion sickness. This finding and other experiments lead to renewed interest in an earlier hypothesis that fluid shift to the head in microgravity may contribute to SAS, and that head mass and tilt-sensing mechanisms in the neck may also play a part.

Drugs continue to be investigated as a possible therapy for SAS. In 1986, a total of 26 medications, combinations and doses were tested for their effectiveness in countering motion sickness in patients seated in a rotating chair. Scopolamine combined with

d-amphetamine continues to be the medication of choice for SAS, but drugs that release dopamine were also shown to hold promise as anti-motion sickness therapy. Recent analysis of shuttle test data has also confirmed that orally administered drugs are absorbed differently in weightlessness than in normal gravity. The previous finding that low-dosage intra-muscular injections of anti-motion sickness drugs work without side effects offers an alternative to oral administration.

This pharmacological approach is related to studies of the chemical causes of sensory discomfort. Experiments involving human surrogates, for example, show that the neurotransmitter serotonin, which plays a role in mood and behavior, is linked to motion sickness. Preliminary data also have been collected on the relation of vasopressin (a hormone) and glucose levels to motion sickness.

Training programs and various psychological coping strategies are also being explored as possible countermeasures for SAS and the larger problem of neurosensory adaptation to space. Autogenic feedback training--a method of teaching individuals to directly control their own motion sickness symptoms--was tried onboard the Spacelab 3 shuttle mission in April 1985. Data analysis from that experiment is now complete, and the technique shows enough promise to warrant further testing on future flights.

A simulator that could adapt space crews to the disorientation of spaceflight before they fly is also in the preliminary stages of planning. Called the Preflight Adaptation Trainer (PAT), this device would attempt to mimic the peculiar sensory environment onboard a spacecraft by tilting a visual scene as the subject's head tilts while keeping other sensory cues constant. In its final form, the trainer will have four modes for simulating the altered sensory inputs experienced in weightlessness. The objective is to have vision dominate over the other senses in establishing orientation, thereby diminishing the effect of the neurosensory conflict that contributes to SAS. The next step would be to verify that such training in Earth-normal gravity can be transferred to the microgravity environment.

Cardiovascular System

The cardiovascular system transports blood throughout the body, assists in temperature regulation, delivers oxygen to cells and performs other vital functions. In so doing, it interacts with all body systems, from muscle and bone to autonomic nervous controls.

Body fluids shift headward in microgravity, since there is no force of gravity to pull them down. Heads become congested as fluids migrate away from the legs, and physiological regulators cause an overall loss of body fluid. When the fluids shift back upon sudden reentry into a gravity field, space crews often experience dizziness or are unable to stand upright--an effect that also owes to decreased cardiac output and muscle atrophy.

Cardiovascular researchers have recently used echocardiography to document the fluid adjustments that take place in the heart before a shuttle launch, when astronauts lie in a semi-supine position. Precise knowledge of the "baseline" preflight condition will help in interpreting the effects of microgravity, since it is clear that some cardiovascular adaptation takes place on the launch pad. Echocardiographic experiments also are being conducted onboard aircraft to characterize precisely the fluid shifts that take place in weightlessness.

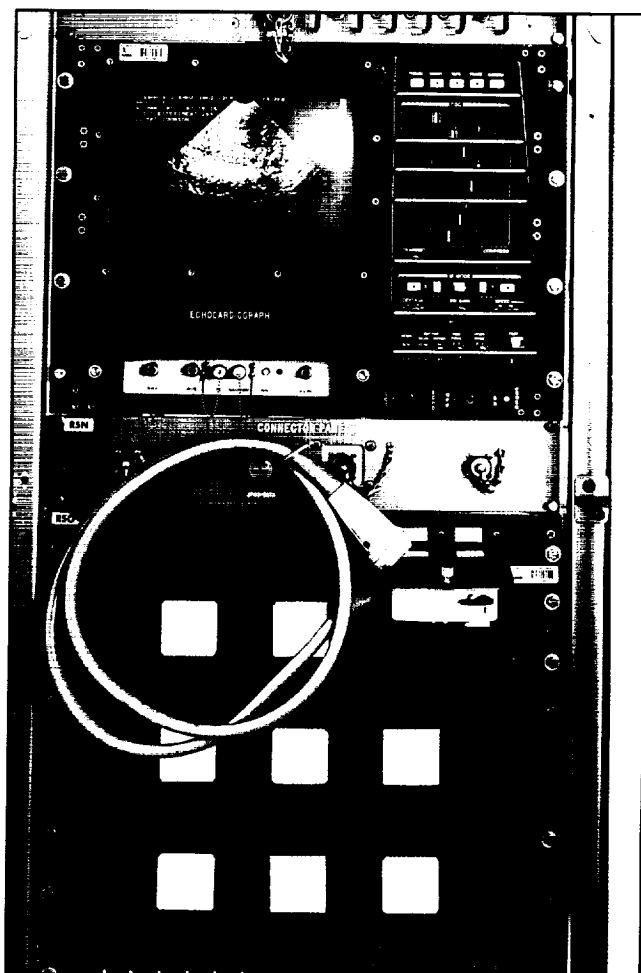
In space, these shifts cause increased blood volume in the heart and a tendency toward lower heart rates. These physiologic changes are studied in detail with sophisticated medical instrumentation. A technique for measuring cardiac output, known as impedance



Owen Garriott performs an experiment on Mission Specialist Byron Lichtenberg to observe venous pressure during spaceflight.



Dr. Rhea Seddon performs cardiovascular measurements on Senator "Jake" Garn during the STS 51-D Mission. Dr. Seddon is using the flight echocardiograph.



The echocardiograph uses ultrasound to produce real-time images of a subject's heart. Part of the LSLE inventory, it will be used in a number of cardiovascular studies on the Shuttle.

cardiography, is being considered as a noninvasive method to monitor heart stroke volume and performance continually onboard a spacecraft. A new device for estimating the body's central venous pressure was also developed recently at the Johnson Space Center (JSC)--a small, battery-powered unit that can operate in the absence of gravity.

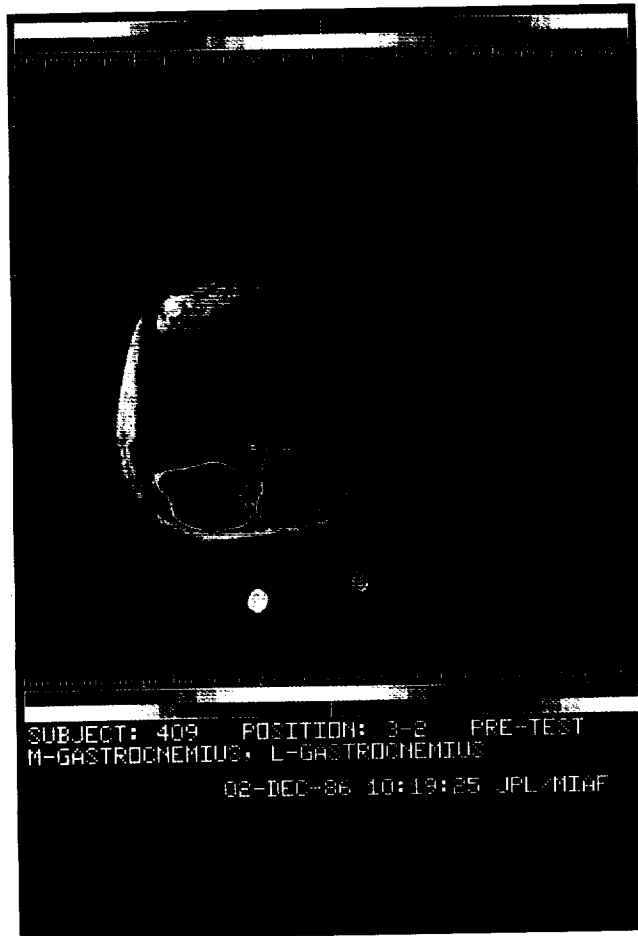
Detailed monitoring of these changes on one or two individuals provides valuable information. However, comprehension usually requires studying a larger test population. An orthostatic intolerance human data base involving subjects of different ages, sexes and degrees of fitness has been compiled at the Kennedy Space Center. This will provide information, for example, on why people with high aerobic exercise capacity seem to faint more easily and have a lower orthostatic tolerance. It also may lead to an understanding of what kinds of exercise, if any, would be best for maintaining orthostatic tolerance in space.

In addition, life scientists at JSC continue to explore methods of preventing fluid shift. Biomedical researchers there are evaluating several candidate lower body negative pressure (LBNP) devices, which force fluids downward toward the legs in microgravity, just as gravity does naturally on Earth.

Bone

Understanding how bone strength, mass and mineral content decrease as a result of spaceflight is an ongoing area of research. Chemical and physical changes seen in the bones of growing rats after only seven days in space indicate how quickly these changes can take place in animals. The loss of bone strength in space poses a risk of bone fractures for crews on long-duration missions, and results from earlier spaceflights raise the possibility that bone degradation as a result of spaceflight may not be reversible.

In trying to understand the effects of microgravity on bone, one area of continuing interest is the structure of collagen, the fibrous protein in bone tissue. Three-dimensional modeling techniques using advanced computers recently showed that the structure of collagen may change due to dehydration, which could be a factor in reduced mineralization.



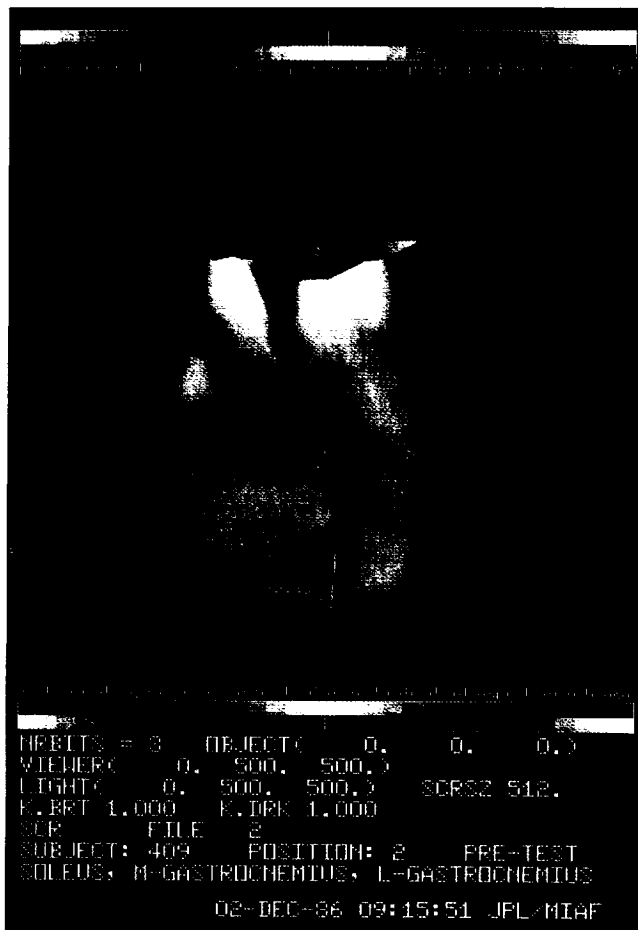
Researchers at the Jet Propulsion Laboratory are developing computer techniques to measure muscle volume from magnetic resonance images. Individual images (60 in total), such as the one above, are manipulated via computer programs to generate a three-dimensional picture of the gastrocnemius leg muscle (right).

Physiologists know that the intestinal absorption of calcium and phosphorus, which are needed by growing animals to form a strong skeleton, is enhanced by vitamin D. Experiments with rodents at the Ames Research Center showed that when two test groups were fed diets without vitamin D that had two different levels of calcium, they both developed bone disease, but the high calcium diets caused a type of disease where the bones are low in phosphorus.

As calcium leaves the bone matrix, it is transported by the blood to the kidneys for excretion. Calcium buildup in the urine poses particular risks for spaceflight crews, who might develop painful kidney stones in flight. Results

ORIGINAL PAGE

BLACK AND WHITE PHOTOGRAPH



from bedrest subjects show that there are pronounced shifts in calcium in soft tissues, plasma and bone as a result of immobilization. Calcium within individual cells increased with bedrest, although this effect was diminished by exercise. Additional studies are planned, detailing and correlating bone calcium loss with clinically observable calcium levels and changes in intracellular calcium content.

Researchers continue to collect basic data on the relation of bone mineral to strength, and to explore dietary and pharmacologic countermeasures to changes in bone metabolism. Results from a 5-week bedrest study conducted in 1985-86 indicate that fluoride may be effective in slowing bone mineral loss if administered prior to immobilization. Subjects who received slow-release fluoride treatments for four weeks prior to bedrest had only half the bone mineral loss of control groups. While preliminary, this kind of research may lead not only to solutions

for spaceflight, but also to new treatments for bone-degrading diseases on Earth.

In support of such bone studies, engineers at the Jet Propulsion Laboratory have developed a new type of digital radiography scanner for radiologic imaging that will allow researchers in laboratories to achieve extremely precise and accurate bone mineral measurements. The scanner achieves high resolution with substantially lower radiation dosages to the patient, and may have applications in other clinical settings here on Earth.

Muscle

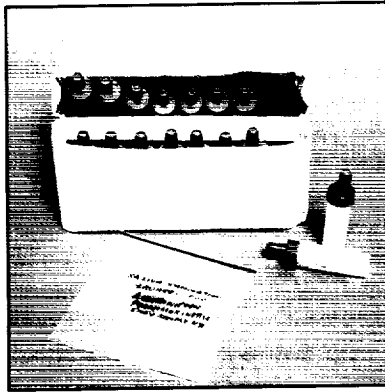
On Earth, gravitational force requires that leg and other postural muscles perform a certain amount of work just to keep the body standing upright. In the absence of gravity, space crews need to exercise with devices such as bicycle ergometers and treadmills to maintain even a basic level of muscle tone. Exercise is currently the only accepted countermeasure for muscle atrophy in space, but may not prove effective for axial postural muscles.

Basic research continues toward determining the rate and extent of atrophy and recovery from atrophy, as well as clarifying the physical and chemical mechanisms that regulate muscle mass and performance. One recent study found that protein synthesis in immobilized muscle decreased 67 percent in only a few hours, but returned to 100 percent levels two days after resuming normal mobilization. In another experiment, Clenbuterol, a pharmacologic agent, was shown to decrease atrophy of soleus muscles in rodents by almost 20 percent over a two-week period.

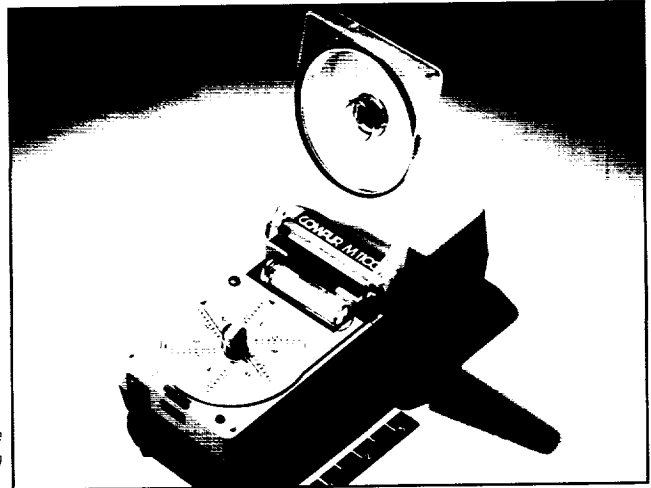
Research physiologists at several NASA centers are now determining the exercise regimens that will be used onboard the Space Station as a countermeasure to muscle atrophy. An initial exercise prescription for long duration spaceflight has been completed, and a preliminary survey of possible exercise devices, including bicycle ergometers, treadmills and rowing machines, has been conducted. In addition, computer systems for monitoring exercise and setting conditioning protocols are being explored.

In their attempt to find new ways to mimic the effects of weightlessness, NASA researchers also recently conducted limb casting studies, immobilizing the legs of subjects to induce

Saliva collection
kit for
inflight pharmaco-
kinetics studies.



This small blood centrifuge unit is part of the Life Sciences Laboratory Equipment inventory and has been used on several Shuttle missions.



atrophy similar to that which occurs in space. Pilot studies of electromyostimulation (EMS)--a technique for stimulating muscle contraction with very slight electrical currents--as a countermeasure to atrophy were also conducted, in an attempt to determine such basic factors as which frequencies should be used for stimulation, how much and how often. Researchers now plan a more comprehensive series of tests where voltage-controlled EMS will be applied to quadriceps, hamstring and calf muscles, to determine the effects on muscle size and density, as well as leg strength and endurance.

Immune and Endocrine Systems

Evidence from shuttle flights shows that space travel leads to changes in the body's immune system, including reducing the numbers and effectiveness of lymphocyte cells that produce infection-fighting antibodies. The clinical significance of this finding as it pertains to spaceflight has yet to be determined. Fluid shifts also result in changes in the way hormones and electrolytes are distributed in the body. These and other aspects of the body's biochemical controls require detailed studies.

Using blood samples taken on the Spacelab 2 mission in 1985, scientists have made the first inflight measurements of atrial natriuretic factor (ANF)--a peptide believed to play a role in

controlling body fluid volume--in human plasma. ANF was seen to increase early in the flight, but later decreased significantly from preflight levels. Ground-based experiments of ANF plasma levels also are being conducted. Using a lower body negative pressure (LBNP) device that "pulls" fluids toward the legs, researchers are studying the effect of fluid shifts on ANF production and serum concentration. Preliminary results suggest that lower body negative pressure decreases ANF levels.

Results from a seven-day study of the metabolic effects of bedrest showed that changes in muscle metabolism occur. These include lower glucose tolerances and decreased responsiveness to insulin, the hormone responsible for control of blood sugar levels. Insulin resistance appears to be confined to muscle, which showed a 5-8 percent decrease in volume and a 3-5 percent increase in fat after a week of bedrest.

Urinary chemistry studies have revealed evidence that moderate physical exercise may enhance the formation of kidney stones, possibly due to dehydration--a finding that would have significance on Earth as well as in space. While dehydration, increased calcium excretion and diet have long been known as factors in stone formation, their impact and consequences during spaceflight are unclear.

Bedrest Studies

Many of the Life Sciences Division's space physiology investigations address more than one body system. Studies of the cardiovascular effects of weightlessness, for example, may overlap with studies of the endocrine system or muscle.

Bedrest studies are an accepted way of simulating some of the inter-related physiological effects of microgravity. Patients lying in bed for long periods experience muscle atrophy due to the "unloading" of postural muscles, and the head-down tilt protocol used in space-related bedrest research mimics the headward fluid shift that occurs in weightlessness.

Two 30-day bedrest studies were conducted in 1986 at the Ames Research Center to investigate the effectiveness of different exercise programs in maintaining fitness during prolonged periods of inactivity. The goal of this type of study is to develop a recommended exercise prescription for crews in space, should exercise prove to be the countermeasure of choice.

Nineteen men, aged 32 to 42, were divided into three groups, all lying supine with heads tilted downward at a six degree angle to simulate the headward shift of body fluids that takes place in weightlessness. A control group performed no exercise at all during the month of bedrest, while the other two groups exercised at peak levels for one hour a day while lying down.

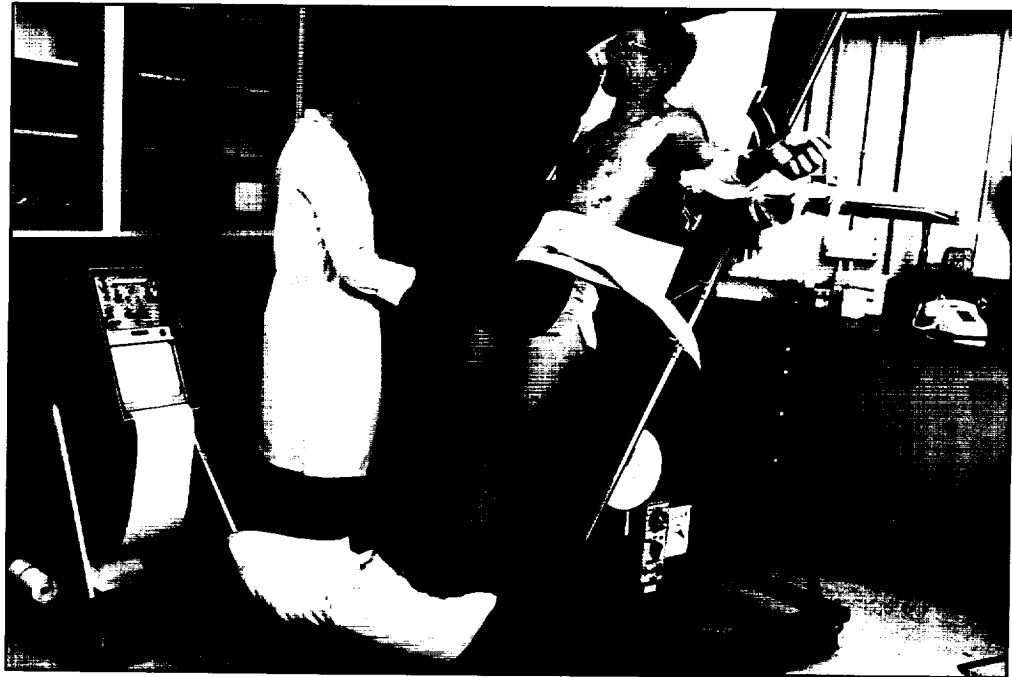
Fitness was measured in terms of physical work capacity-- defined in terms of maximal oxygen uptake--as well as muscle strength. Data were also collected on muscle biochemistry and atrophy, bone mineralization and density, calcium levels, hormonal responses and fluid balance, psychological factors and the subjects' ability to stand and walk unimpaired after a month in bed.

The exercise programs were designed to keep test subjects at normal fitness levels despite their inactivity. In these investigations, a clear training specificity effect was found--certain exercise programs maintained muscle strength, while others maintained physical work capacity.

Magnetic imaging and ultrasound measurements showed a decrease in leg muscle mass during bedrest, which varied among muscle groups and depended on the type of exercise program. As expected, there was no decrease in bone density, but a small net fluid loss and a reduction in body weight were noted.

Bedrest also lowered the subjects' orthostatic tolerance, and exercise did not improve their ability to walk or stand unimpaired in the period immediately after the month of bedrest ended. This strongly suggests that countermeasures other than aerobic exercise may be required to solve this problem.

To better understand the mechanism of orthostatic intolerance, effects of sudden vertical positioning after 30 days of bedrest are studied.

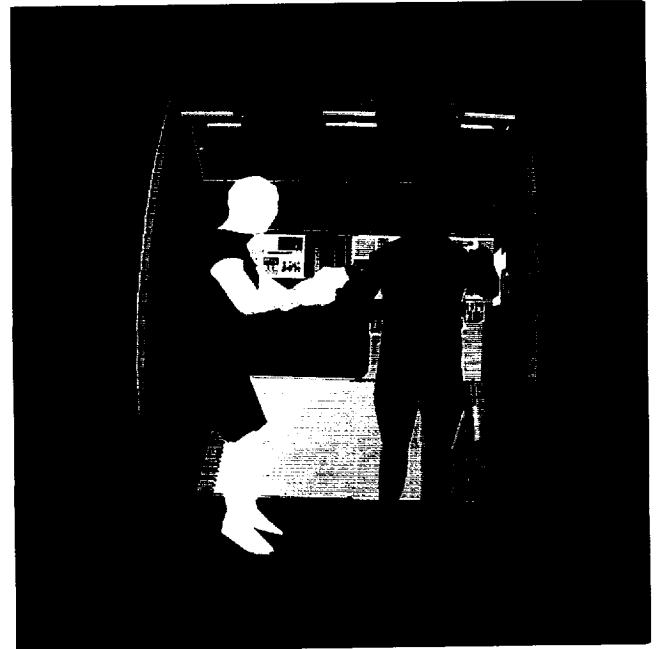


Crew Behavior and Performance

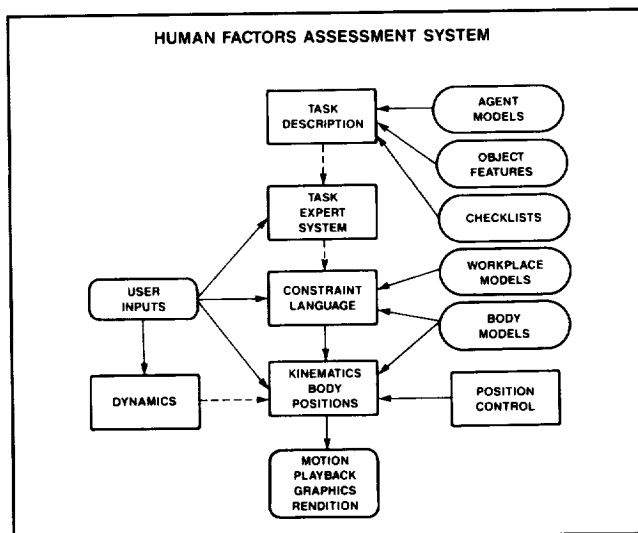
The Space Station will be an evolving facility that must be adaptable to different kinds of users and needs over the course of many years. The Anthropometrics and Biomechanics Lab (ABL) at the Johnson Space Center contributes data on how machines, displays and mechanical interfaces onboard the Station or other spacecraft should be designed for most efficient and productive use by the crew. To avoid costly design changes after a prototype is built, the ABL simulates the environment of a spacecraft for use by designers early in the planning process.

One problem addressed in this research is the physical reach of a person in microgravity, where the body assumes a floating position known as neutral body posture. Displays, cabinets, and controls must all be within the "reach envelope" of the crew. Researchers at the ABL also study the reach and strength capabilities of space crews testing prototype space suits for the 1990s, and set the physical limits for the construction and assembly jobs that will be needed to build the Space Station in orbit.

To assist them in these studies the ABL uses sophisticated computer models of spaceflight



Computer-generated images of crew members in the Space Station allow engineers and researchers to test human compatibility with various designs and configurations on a display screen -- obviating the need to build costly models until suitable designs have been selected. This simple frame depicts two crew members at a work station. By generating and linking subsequent images, researchers have a "motion-picture" view of people working in and around the envisioned Space Station.



Man-Modeling for Crew Space Station Design. The Human Factors Assessment System is part of a multi-year program in complex computer simulations development at the Johnson Space Center and the University of Pennsylvania. The block diagram shows the various modules and their relationships used to formulate a "hierarchical reasoning" procedure to allow modeling of task performances at various levels of detail. Dashed arrows indicate the undetermined relationships presently being researched.

crews--animated graphics based on actual mission films. These computer models, called PLAID and TEMPUS, are periodically upgraded in terms of the number of parameters that can be included in a given problem. The ultimate goal is to develop a predictive model of human kinetics and dynamics in microgravity.

Space Station planners are also studying the social and psychological factors relevant to the Station design--how, for example, the "public" areas should be arranged, or how color schemes in crew quarters can be modified to assist in maintaining health and performance. In these studies, psychologists consider such matters as how to ensure privacy in very small spaces, and how viewports and open passageways affect the psychological well-being and performance of the crew.

Psychological and social factors of spaceflight are of great concern to NASA planners who are considering sending crews on lengthy round trips to Mars or long-duration stays at a Space Station or lunar base. Crew members on such missions will be asked to perform risky and demanding jobs while living in confined and isolated environments beyond Earth. Crews will

be drawn from a diverse pool of applicants, and will represent a mix of social, intellectual and cultural backgrounds.

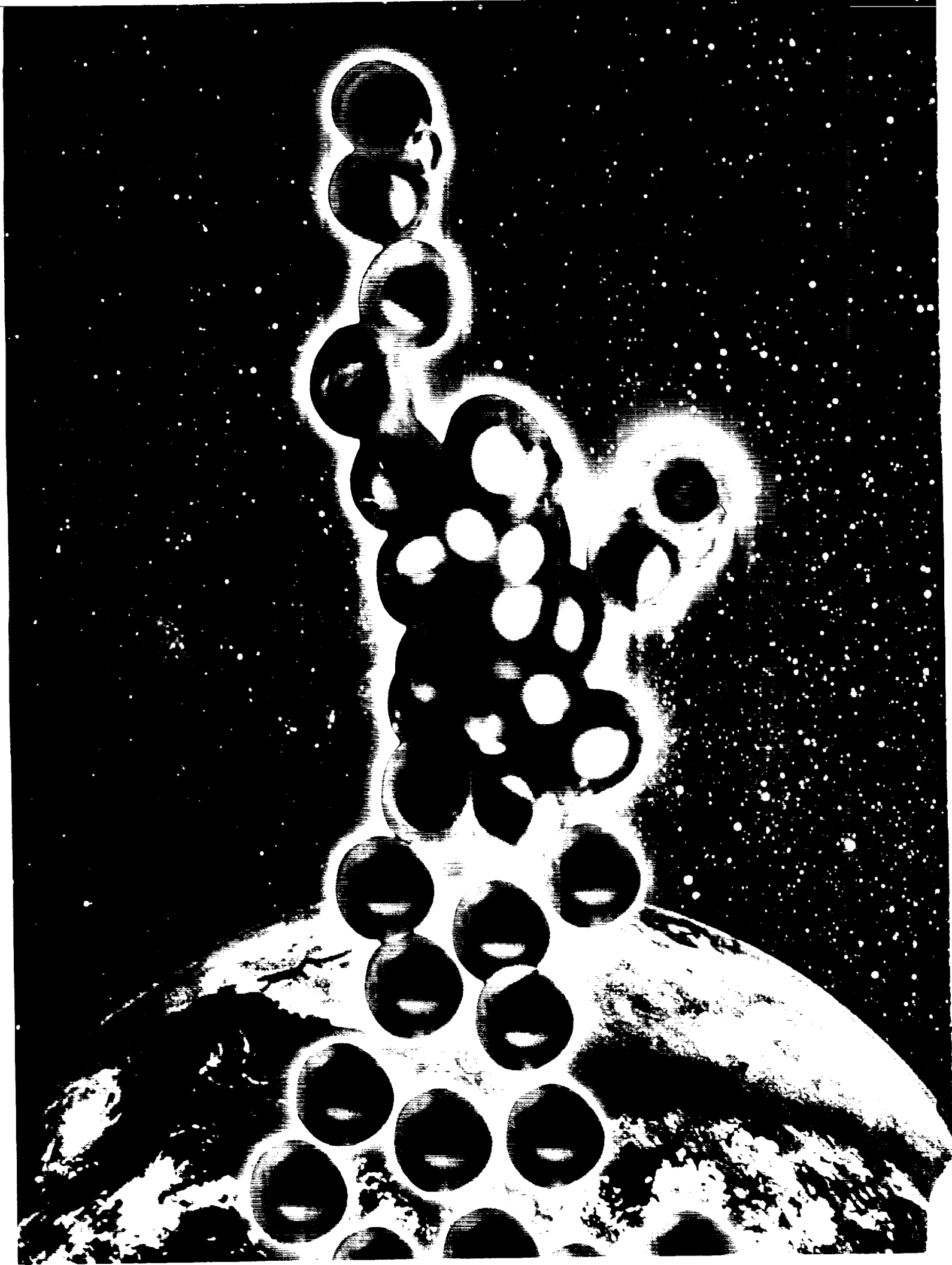
Although Soviet cosmonauts have stayed in orbit for up to eight months at a time, the longest American spaceflight to date is the 84-day Skylab flight of 1973, one of only three U.S. missions to last longer than two weeks. A lack of sufficient data from these few prolonged spaceflights has led researchers to study the behavior of subjects living in environments on Earth that compare to anticipated long-duration missions in space.

In their search for terrestrial analogues to spaceflight, psychologists are studying crews on nuclear submarines, at Antarctic outposts, and in other isolated situations.

An observational study was begun recently of North Sea diving teams who work for several weeks in pressurized environments 200 meters underwater. A major conference on the psycho-social dynamics of Antarctic bases was also held in 1987. In addition, studies have been initiated to identify leadership qualities and team dynamics for space crews.

The results of these and other space biomedical research investigations contribute to the Life Sciences Division's mission of enabling human beings to adapt to the new and hazardous environment of space. Only by learning more about the physical and psychological effects of spaceflight are we able to venture beyond the planet on which our species evolved.





Gravitational Biology

All terrestrial organisms evolved in a one-g gravity field, one of the very few constants of life on Earth. Skeletal frames, balance organs and the trunks of trees--all developed as a means to withstand and adapt to the incessant downward pull of gravity.

By going into space, humans, animals and plants have experienced life without this pervasive environmental factor, and in so doing have opened new territory for life scientists to explore how gravity shaped life as we know it. If humans are to journey to other planets or make even more ambitious plans for the settlement of space, then the most basic questions of how gravity influences living organisms must be answered.

The study of how plants and animals interact with gravity begins with the basic question of how they sense their position and motion in the presence (or lack) of a gravity field. This research area deals with such questions as: What are the gravity-sensing systems in plants and animals? What role has gravity played in their development and evolution? What are the biochemical and physical mechanisms by which sensory information is transduced, processed, transmitted and integrated into a response? How do gravity-sensing mechanisms function and adapt to weightlessness?

A second area of research focuses on the ways in which terrestrial organisms have adapted to Earth's gravity and how they change when the force of gravity is suddenly removed. What influence has gravity had on the evolution of organisms, their biological support structures, metabolism, fluid dynamics and biorhythms? What is the interaction of other environmental factors with gravity? How do animals and plants adapt to being weightless?

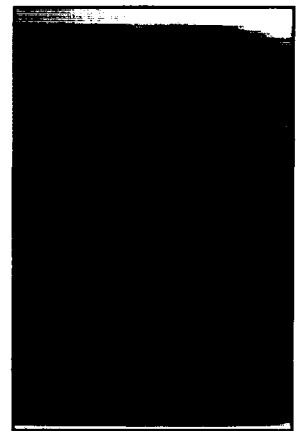
Developmental biology studies focus on determining the influence of gravity on reproductive and developmental processes, from mating to fertilization to early development of an embryo and growth through subsequent generations. How does gravity affect the growth and aging of individual organisms? What developmental stages or systems are affected by gravity? And finally, will species grown over several generations in space be able to produce normal offspring, either in space or back on Earth?

Plants

On Earth, plant roots as a rule grow downward toward gravity, while stems grow up and away from gravity--a phenomenon known as gravitropism. By studying weightless plants onboard spacecraft, biologists seek to understand the fundamentals of how plants respond to gravity, and how that response can be modified by other factors, including radiation, light, temperature and mechanical stress.



Phototropism - Plant orients and grows toward light source

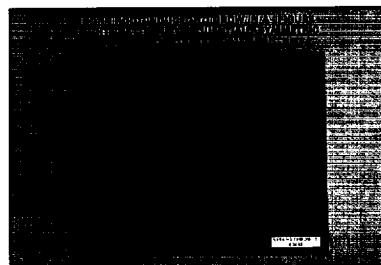
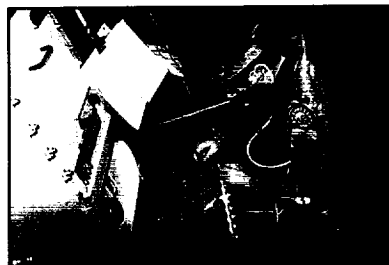


Geotropism - Plant orients itself with the gravity vector - roots growing towards and photosynthetic parts away from source of gravity.

On Earth, frog egg development is influenced by its orientation in gravity. In the absence of gravity in space, the frog egg cellular components can no longer orient themselves correctly, posing intriguing questions for biologists.
Artist: Jon Lomberg

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COLOR PHOTOGRAPH

Payload Specialist Ulf Merbold plants seeds during the orbit of Spacelab One mission.

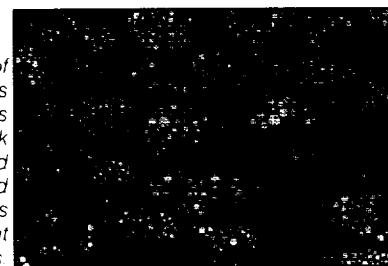


This corn root was induced to grow in a "Figure-8" pattern by applying a calcium solution to selective portions of the growing root.

Although accelerations can be altered on Earth by such devices as centrifuges, clinostats and experimental aircraft flights that simulate weightlessness for a very short time, biological research into the effects of microgravity can only be done in Earth orbit. Experimenters continue to prepare for flight opportunities, and have completed preliminary baseline studies with such plants as sunflower, maize, oats and day lily for later use in flight experiments. Yeast strains are also being developed for use in genetic tests in space and on the ground.

Plants react to gravity first by sensing its direction via sensing cells, then by converting what is sensed into physiological signals, then finally by transmitting signals from the sensing cells to the part of the plant that actually bends.

This photomicrograph of stained plant cells shows the amyloplasts (distinctive small dark bodies) sedimented toward the bottom end of the cells. Amyloplasts are thought to be plant gravity receptors.



Photograph courtesy of Dr. Michael Evans, Ohio State University.

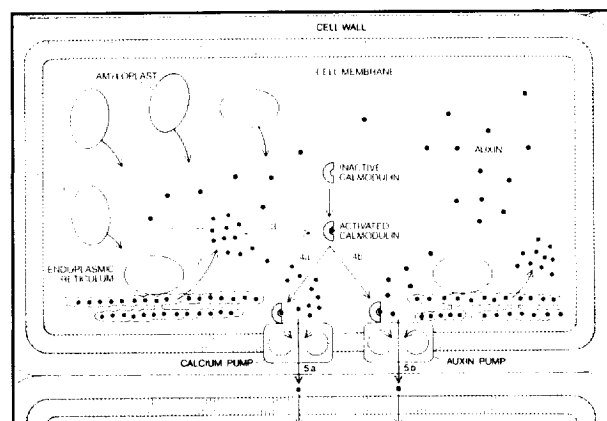
The bending of a horizontal root is caused by the upper side growing faster than the lower side. Hormones called auxins are believed to control the rate of cell growth.

Starch grains called amyloplasts have generally been thought to be the primary gravity sensors in plant cells. According to theory, gravity causes the amyloplasts to settle,

A Proposed Model of Sensing and Transduction Stages of Gravitropism

This model proposes how amyloplast sedimentation in gravity-sensing root tip cells might lead to downward movement of both calcium and auxin. When a root is turned on its side, amyloplasts (being denser than the surrounding cell fluid, or cytoplasm) drift down under gravity's influence to the lower side of each cell. In this model, the falling amyloplasts make contact with the endoplasmic reticulum, a membrane system, on the lower cell edge. The pressure of the amyloplasts on the endoplasmic reticulum causes a release of calcium ions into the cytoplasm.

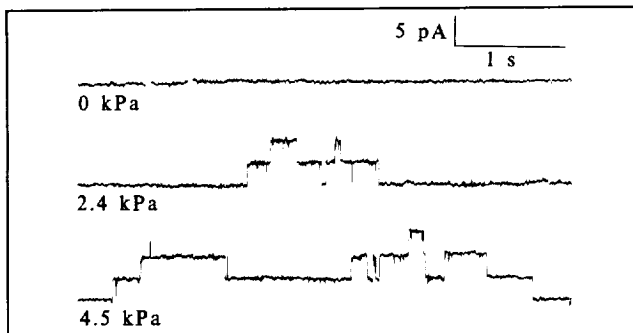
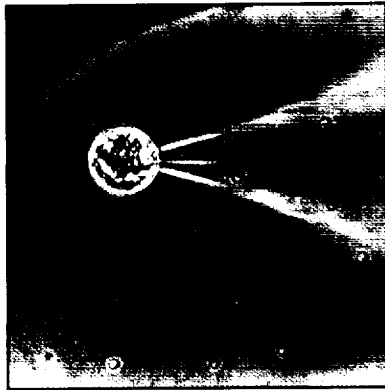
Calcium ions bind to and activate a special protein called calmodulin. The activated calmodulin in turn activates two membrane pumping systems: a calcium pump and an auxin pump. These two pumps actively move auxin and calcium toward the lower side of the root tip. From there, the excess of growth-inhibiting auxin is transported along the lower side of the root where it inhibits growth, thus causing the root to bend downward.



This figure graphically displays the sequence of cellular events which may take place and explain why roots grow downward in a gravity field. Amyloplasts (1) drifting down onto the endoplasmic reticulum cause calcium (red dots) to be released (2). This calcium activates calmodulin (3) in the cell which, in turn, activates calcium pumps (4a) and auxin pumps (4b) on the lower cell surfaces. These pumps transport, respectively, calcium and auxin (black dots) through the cell membranes (5a and 5b) to the lower root surface.

From: "How Roots Respond to Gravity" by Michael Evans, Randy Moore, and Karl Heinz Hasenstein
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Photograph of a "patched" tobacco plant cell. A patch is achieved by gently sucking a plant cell, whose cell wall has been removed, to the tip of a pipette, the cell membrane then adheres to the glass rim. Current passing through the patch is recorded via an electrode.



Trace recordings of discrete pulses of current recorded when patched plant cells are subjected to gentle suction or pressure. The pulses shown above represent the opening of membrane ion channels in response to two different levels of applied pressure. Channels such as these may be the mechanism whereby the physical force of gravity is transduced by plants into a chemical/electrical signal.

which triggers the gravitropic response in some way that is still not well understood. Recently, though, evidence against amyloplasts as the gravity sensor has been obtained. A particular mutant of the *Arabidopsis* plant, even though it contains no starch, has been found to respond to gravity nonetheless.

At the same time, there is new evidence for amyloplasts as the gravity sensors. The only place in dark-grown stems where sedimented amyloplasts are consistently found is in the part of the stem that bends with gravity. Researchers have recently discovered microfilaments around both the amyloplasts and the nuclei of shoot and root cells that contain amyloplasts, which may give new clues to how amyloplasts function.

Previous studies have shown that minute changes in electrical current in plant roots play a key part in the sensing of gravity. While the precise ways in which these changes occur are still being investigated, some new information has been uncovered. Exciting work has been conducted with stretch membrane channels,

which allow more ions to pass through cell membranes in response to stretch and other factors. One such channel has been known to exist for some time, and a second stretch-activated channel was found recently. (The technique used in these experiments, called "patch clamping," is illustrated in the figure to the left.) These stretch-activated channels may serve as the mechanism in plants for the mechanotransduction of gravity and other physical forces.

The electrical changes are inhibited if the protein calmodulin, a calcium regulator, is inhibited, but not if auxin, a critical plant growth hormone, is inhibited. This points to the movement of calcium ions as a factor in gravity sensing. Calcium has been shown to play a major role in the next step of the gravitropic response--the conversion into an actual physiological signal within the sensing cell. It also has been linked to the stunting of plant growth as a result of mechanical stresses such as vibration.

Interaction of calcium and calmodulin with a nuclear enzyme has also been demonstrated for the first time. An enzyme involved in the synthesis of messenger RNA (ribonucleic acid) was shown to be stimulated by calcium-activated calmodulin.

Gravity is not the only environmental factor that controls plant growth. Some roots, for example, don't respond to gravity unless they are illuminated. In these plants, too, calcium is a factor: the level of calmodulin increases rapidly following illumination. Furthermore, vitamin D, which induces calmodulin synthesis in plants, can cause the gravitropic response, which can also be restored by very low levels of red light--basic knowledge that may be of interest to those designing plant growth chambers in space.

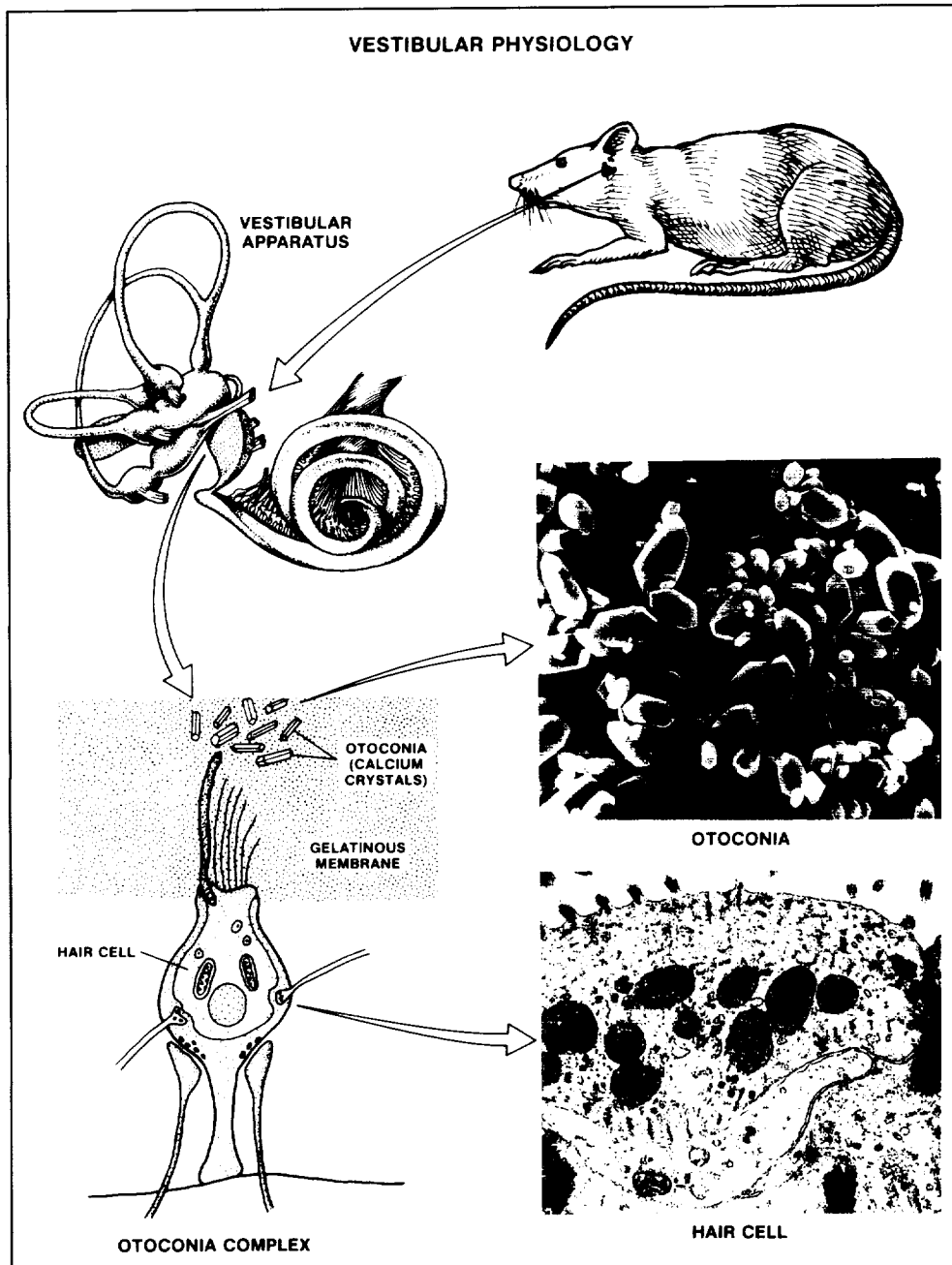
Researchers are now on the threshold of synthesizing all of this information and producing models which can then be tested experimentally. One such model, explaining the possible sequence of actions in the sensing and transduction stages of gravitropism, is illustrated on the previous page.

Time-lapse photography and microprobe measurements of growing cucumber stems have revealed that bending due to gravity is caused exclusively by changes in the yielding properties of cell walls rather than by shifts in

fluid pressure within the cells. This loosening of the cell wall is quite pronounced, increasing severalfold within a few minutes. The importance of this discovery is that it now allows scientists exploring the most basic mechanics of gravitropism to focus on ionic and enzymatic changes within the cell wall. Recent work also has shown that the outer, epidermal layer of cells must be present for roots to respond to gravity.

Animals

All animals have gravity sensing organs--biological accelerometers that orient them and help them maintain balance in the Earth's gravitational field. In vertebrates, these organs are found in the vestibular system of the inner ear. Two fluid-filled chambers--the utricle and the saccule--have areas called maculae lining their walls, which contain sensory cells. These cells are connected to nerves on one end, and have small projections, called



Research efforts focused on gravity receptors in mammals may be of value in understanding and treating otolith organ disease and in ensuring the health and productivity of space crews.

stereocilia, on the other. When otoliths--tiny calcium carbonate stones suspended in fluid--brush against the stereocilia, impulses travel to the brain that give the animal information about its position relative to gravity and linear acceleration.

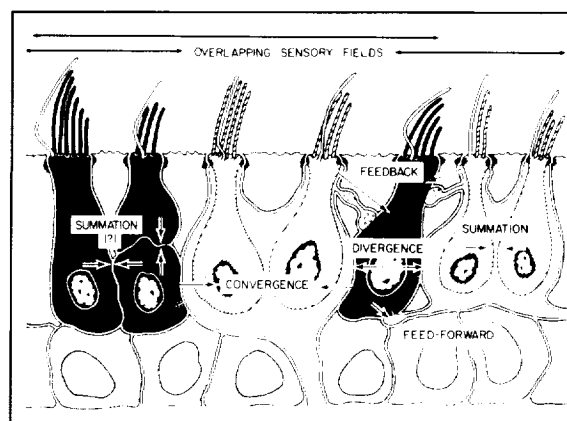
Detailed anatomical studies and modeling of the nerve terminals and hair cells of the maculae by scientists at the Ames Research Center have led to exciting new insights into how these gravity sensing organs process information. Three-dimensional reconstructions of the maculae indicate that they act as small parallel processing units, with certain cells distributing signals to more than one nerve in a primitive neural network. There appear to be different kinds of nerve/terminal patterns as well. Complex processing of encoded signals is therefore taking place at the cellular level, with information traveling to the brain at slightly different times, via parallel nerves. Aside from its biological significance, this work may also be of interest to computer scientists attempting to design advanced decision-making machines.

In the hair cells of mammalian gravity receptors, the transfer of current is accomplished almost entirely by potassium ions in the inner ear fluid. Recent experiments show that the activity of a key ion transfer enzyme is elevated in the utricle, but not in the other fluid-filled chamber of the inner ear, the saccule. This supports the notion that fluid balance in the saccule is maintained from outside the saccule chamber, and advances scientists' understanding of basic electrochemical mechanisms of the inner ear.

Experiments with less complex animals also provide fundamental information about how electrical current flow relates to gravity sensing. Work with mollusks has led to the first direct recordings of a single ion channel from a graviceptor nerve cell. The recordings show that the channel, which transports potassium ions, is "open" much of the time.

Electron microscope studies of developing chicken embryos have given new insights into how and when gravity receptor structures crystallize, or calcify. The process appears to be gradual, with intermittent periods in which it accelerates. These results may be applicable to the study of other calcifying tissues such as bones and teeth.

In preparation for flight experiments, computer hardware and software are being developed to collect vestibular data from rats in space. At the same time, researchers are conducting basic physiological experiments to gather data on the vestibular system of rats on Earth.



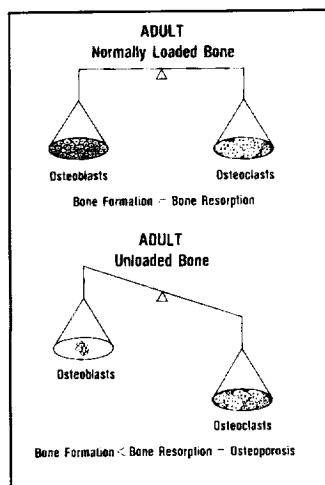
Hair cells of the maculae. Work with long series of sections shows that gravity receptors process information in parallel, much as computer information networks do.

Earthly Benefits From Space Research

Computer scientists at the forefront of designing "smart" machines have long held the human brain as the ultimate example of an information processing system that is both complex and fast. The most advanced computers are still primarily serial processors, handling information in sequence. The brain, however, uses a network of billions of neural connections to process information in parallel, greatly increasing its speed and power.

In their search for an analog to the human brain, computer scientists have looked at other, simpler natural "processors"--the retina of the eye, for example. But even the retina is enormously complex. The discovery that gravity-sensing cells in mammals also act as parallel processors gives scientists a much simpler device to study.

The gravity-sensing cells in mammals form a "weighted" neural network, where the number of connections is as important as the actual pathways of information. Experimenters now hope to produce a dynamic model of that functioning network, which could be used by computer scientists as a model to design machines capable of artificial "intelligence".



Bone-forming cells (osteoblasts) and bone-resorbing cells (osteoclasts) are in balance in normally loaded bone, and no net change occurs. When bone is unloaded, however, a greater proportion of osteoclasts leads to a net bone resorption.

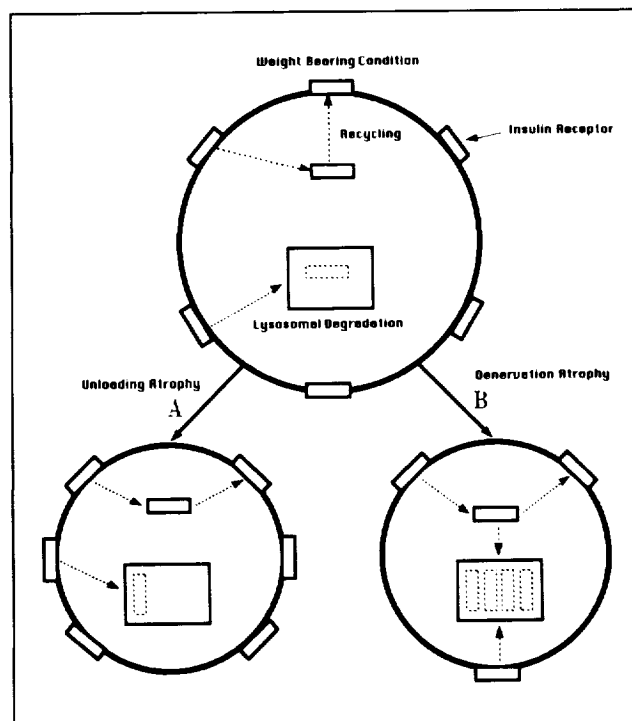
These gravitational biology studies also support more applied work aimed at understanding and preventing the harmful effects of weightlessness. It is well known that in both rats and humans, muscles atrophy and bones become degraded when the force of gravity is absent. Bone is formed through the action of special cells called osteoblasts, while it is degraded or resorbed by other cells called osteoclasts. Normally these two types of cells are in equilibrium, but this balance is disturbed when the force of gravity is removed, either on the ground or in space (see figure above). Under these conditions, osteoclasts appear to remove bone mineral first, then degrade the organic matrix that holds the mineral. Newly analyzed spaceflight data and current ground-based work with rats have provided new insights into the reasons for these potentially serious musculoskeletal problems.

Bone growth in rats who experience simulated weightlessness is not influenced by dietary calcium, according to experimental results. Although calcium must be present at a level of more than 0.1 percent in the diet for bone growth to proceed normally in young rats, the calcium only influences bone growth if the bone is being stressed by gravity. Also, the pull of muscles on bones has been seen to partially protect against bone growth defects in rats undergoing simulated weightlessness.

Previous work aimed at defining the events that lead to bone loss in space has shown changes in both the quantity and quality of bone in growing animals after only one week in orbit. These experiments point to mineralization of the protein collagen as a critical stage in the

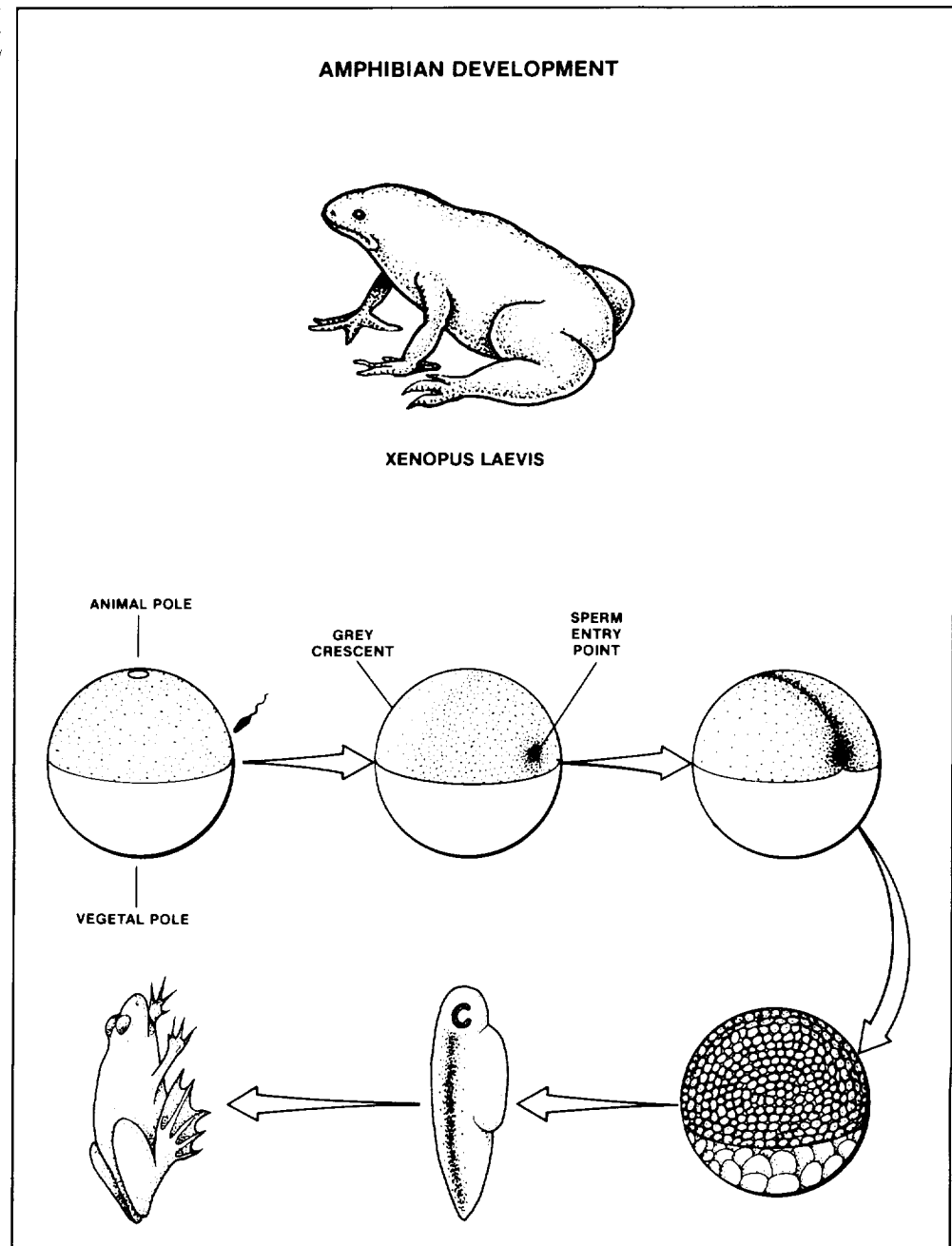
adaptation of bone metabolism to weightlessness. When growing rats are subjected to simulated weightlessness, the arrangement of collagen fibers within the forming bone appears different from normal when viewed under an electron microscope. There also appears to be an increased blood supply to the bones, which could affect their mechanical strength.

Atrophy of muscles in space is another area of great concern to NASA life scientists. Recently, experiments have been conducted to look at the effects of muscle atrophy on the entire neuromuscular system, which includes peripheral nerves, the motor end plates where nerve and muscle interact, the spinal cord and the areas of the brain that control muscle function. One such study demonstrated that there are dramatic changes in the motor end plates of muscles in rats who experience simulated weightlessness. Nerve terminals were distorted and showed large, translucent cavities that indicate degeneration. Further research on the effects of disuse must therefore focus on more than just the muscle itself.



Insulin receptors of muscle can be either recycled or permanently degraded by cell organelles called lysosomes. Atrophy caused by cellular degradation and recycling are constant, and binding capacity is preserved (A). Atrophy due to cutting the nerve supply may lead to loss of receptors, however, due to increased degradation by lysosomes (B).

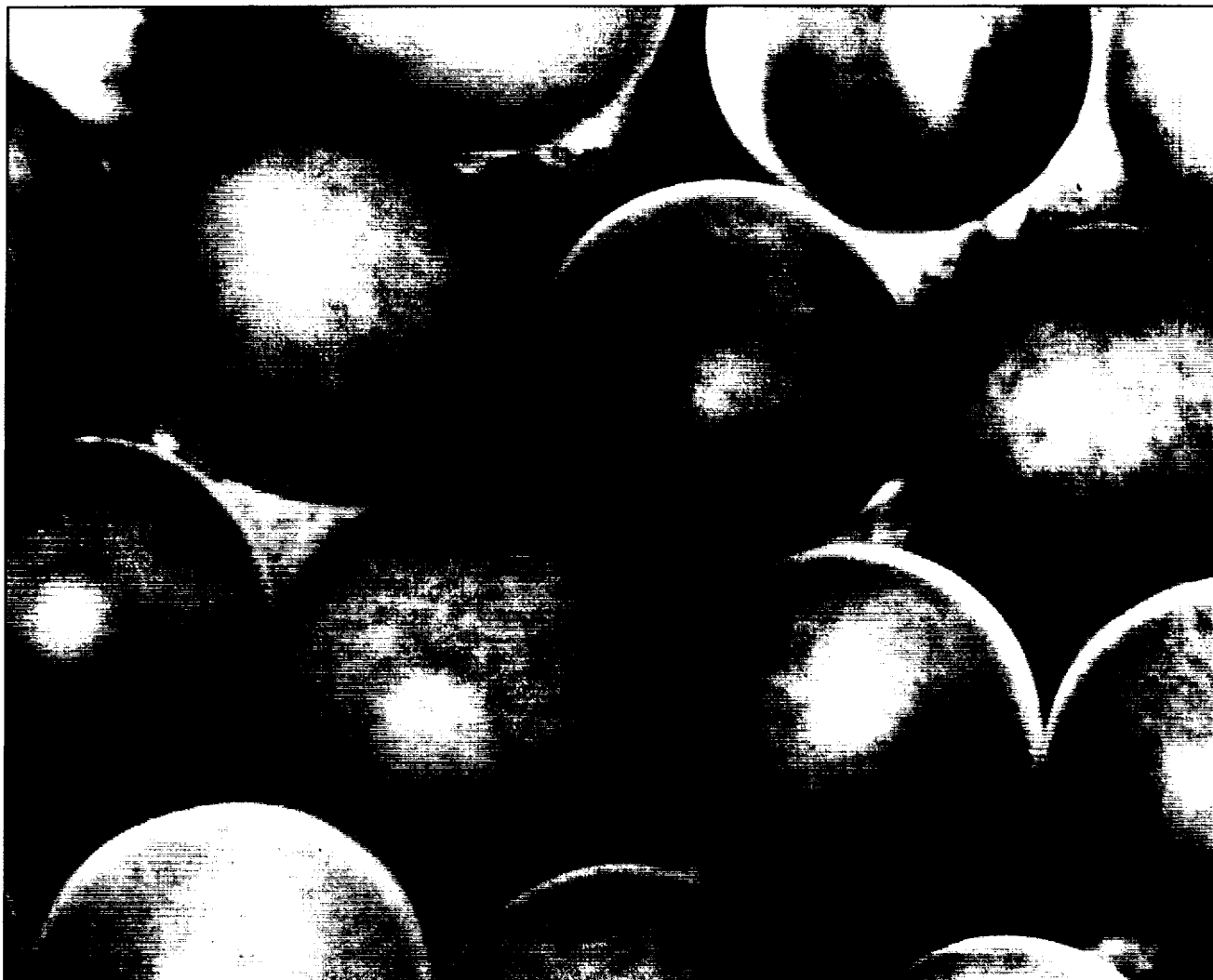
Gravity influences egg development of many amphibian species. Cell constituents of the egg are segregated by density -- the dark less dense material rises to the upper half of the sphere while the denser light-colored material settles to the bottom. Continued development of the embryo follows this orientation.



Muscles that atrophy due to lack of mechanical stress also show an increase in sensitivity to insulin. The change occurs rapidly, but the muscle quickly returns to normal once gravitational stress is reintroduced. Progress has also been made in our understanding of the role of the insulin receptor in muscles, and a model has been proposed to explain different results observed in muscle where the nerve supply has been cut versus muscle that has been "unloaded" so that the stress of gravity is

removed. While no differences in recycling of the receptor are thought to occur under the two conditions, increased cellular degradation of the receptor by lysosomes apparently occurs in denervated muscle, a change which does not occur in unloaded muscle.

Fertilization and development of eggs is another fundamental biological process that may be influenced by changes in the force of gravity. Amphibians make particularly good test subjects for developmental studies, because the



View of frog eggs from above. The darker hemisphere is oriented upward in gravity, the lighter-colored half, downward. Research plans on a future flight call for fertilizing amphibian eggs on orbit, then following their development, uninfluenced by gravity.

distribution of cytoplasm within the egg cell determines the form and structure of the resulting animal.

Shortly after fertilization, amphibian eggs rotate so that the yolk side is down. It has now been learned that the constituents that redistribute within a fertilized egg when it rotates have different mobilities, which do not correlate with the yolk density. When the eggs are prevented from rotating normally, those with low-mobility material nearly always failed to develop. The degree of mobility does not appear to be genetically determined, however, and a female may shed eggs of one type or the other on different occasions. The physiological factors responsible for this variation are not yet

known and will be studied in future spaceflight experiments.

Studies of the precursors of mammalian egg cells, called oocytes, have shown that changes in gravitational force affect cell division, and therefore may affect chromosome movement. No abnormalities appear, however, when mature fertilized eggs are subjected to altered gravity.

Other developmental studies have shown that pituitary cells, which are the source of growth hormone, are altered in growing rats exposed to spaceflight; although they contain more hormone, they release less of it into the blood. Rats in simulated weightlessness on the ground show a similar defect.

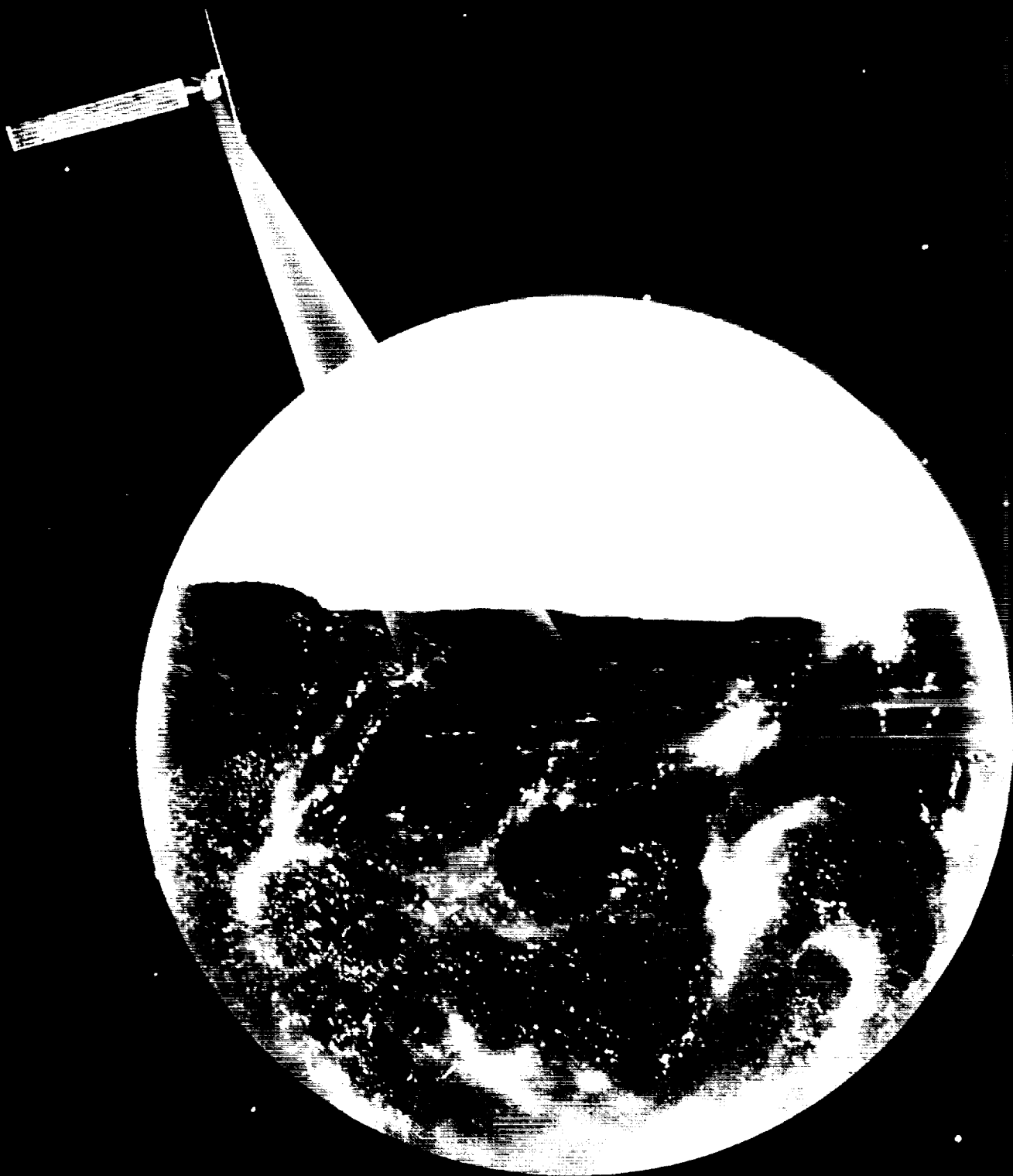
In order to understand the relationship of gravity to biological development, researchers also study the other end of the spectrum--hypergravity. Tests of mice exposed for one year to 2-3 times normal gravity on a centrifuge show that they weigh significantly less than animals raised at 1-g, and grow long bones and skulls with different sizes and shapes. Excess gravity also seems to have an effect on the sex ration of developing fetuses: almost all were female.

Increased gravity affects other body systems beside muscle and bone. For example, the body temperature and biorhythms of growing rats are depressed for days after exposure to increased gravity, and do not synchronize with light/dark cycles as happens with rats in normal gravity.

Guinea pigs have also been subjected to hypergravity and found to be good test subjects, with a higher survival rate for newborns than rats have in similar hypergravity conditions. The guinea pigs show decreased fetal growth at even low amounts of hypergravity, and show marked increases in the growth of leg bones.

The study of how gravity affects plants and animals is one of the most fundamental areas of research in the Life Sciences Division. Just as plant research contributes to the design of self-contained agricultural systems for use on future spacecraft, animal studies overlap the work of biomedical researchers seeking to understand the human body's reactions to weightlessness. Both avenues of research advance our most basic knowledge of how life adapts to its environment.





Biospherics: Studying Planet Earth

Just as robot probes have explored the other planets of the Solar System, Earth-orbiting satellites have given scientists in the space age a more comprehensive view of our own world. From geostationary orbits high above the equator, weather satellites monitor the atmospheric gases swirling and mixing over an entire hemisphere. Earth resources satellites in polar orbit detect patterns in vegetation, solid rock, the oceans and the atmosphere using a wide array of sensors that observe at different spectral wavelengths, while the surface passes below. These remote sensing tools, along with a powerful computing capability, are being applied to the problem of understanding our planet as an integrated biogeochemical system of air, water, land--and life.

Essential biological elements such as carbon and nitrogen follow regular cycles in nature that rely on both living and non-living mechanisms. Atmospheric carbon dioxide, for example, is used by plants for photosynthesis and returned to the circulating air by plant and animal respiration and decay. Today, practices such as the burning of fossil fuels, which introduces carbon dioxide into the atmosphere, are disturbing this ancient balance; precisely how, and how much, is not known.

In 1986, a NASA committee released a report on Earth systems science calling for a thorough and concerted "Mission to Planet Earth" that would study our home planet as an integrated system undergoing change due to human activity. This report was also endorsed by the National Science Foundation and the National Oceanic and Atmospheric Administration. The specific interest of NASA's Life Sciences Division is in determining the role of the biosphere--the realm of terrestrial life--in this complex physical and chemical system.

The Biospherics Program attacks the problem in part by breaking it into specific ecosystems such as temperate forests, tropical forests and wetlands, each of which makes its own contribution to the global picture. For these studies, remote sensing data are collected and compared with "ground truth" results from the

field. These data are then used to develop sophisticated computer programs that model key factors such as the global distribution of trace gases in the atmosphere.

Forest Fires and Atmospheric Gases

Each year thousands of forest fires occur in woodlands around the Earth, some naturally, some caused by humans. Many run their course undetected or unreported. This routine burning of biomass contributes gases such as carbon dioxide, carbon monoxide and methane to the atmosphere, but in what amounts is not well known.

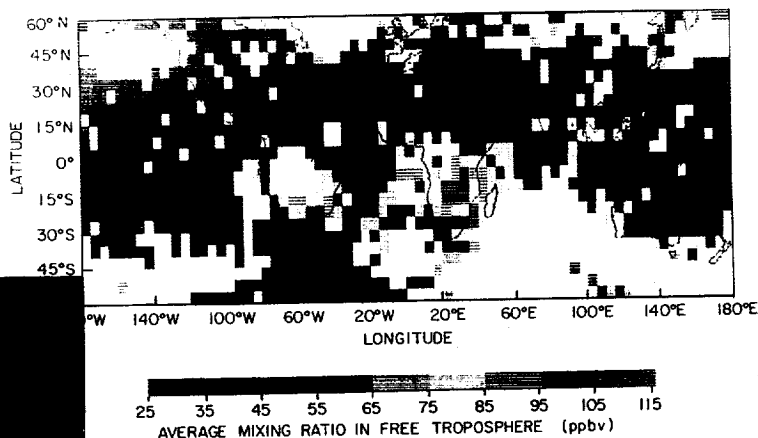
In December 1986, researchers from the U.S. Forest Service, NASA and a dozen other agencies successfully conducted a controlled fire experiment in Lodi Canyon, near Los Angeles. More than 300 acres of chaparral scrubland were burned in the experiment, which was monitored by instruments on the ground and in overflying aircraft.

While aircraft collected gas and particulate samples from within the rising plume of smoke, a multispectral scanner onboard a modified U-2 aircraft observed the plume and fire from above. Images of the burn area were also collected by a NOAA weather satellite in polar orbit. These remotely sensed data can be compared with actual samples and ground observations to identify the best spectral bands for determining the temperature, gas species and production and volume of burning vegetation in this particular kind of ecosystem.

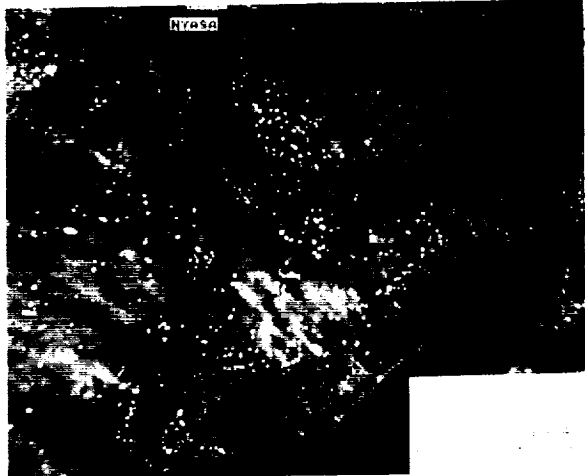
Similar controlled burn experiments are being planned cooperatively among several agencies for other ecological areas, including boreal forest in Canada and subtropical Eucalyptus forest in Australia. One project goal is to conduct an experiment in a tropical forest, where approximately half of all global forest fires occur. The ultimate aim is to devise instruments that could monitor fires, their atmospheric products and ecological consequences from space, based on their spectral properties.

Information from satellite data taken over a one week period is used to plot world-wide carbon monoxide concentrations in the troposphere, the atmospheric layer closest to the earth. A product of incomplete combustion, carbon monoxide is a major constituent of automobile exhaust and major biomass burnings. Notice the high carbon monoxide concentrations in South America and south-central Africa, due primarily to massive fires in those tropical jungle regions.

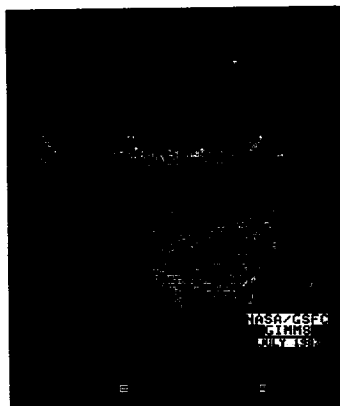
TROPOSPHERIC CARBON MONOXIDE MAPS EXPERIMENT OCT. 5-13, 1984



H.G. Reichle
Atmospheric Sciences Division



This image of Mozambique and Africa's eastern coast was collected by a NOAA-AVHRR imagery satellite on September 26, 1984. The bright yellow spots are areas of major forest fires. Over 600 fires have been counted on this image. Such major burns have serious implications on atmospheric pollutant loading and subsequent effects on the biosphere. Notice that the south-east Trade Winds (from lower right-hand corner) are carrying the smoke and gases towards Central Africa.

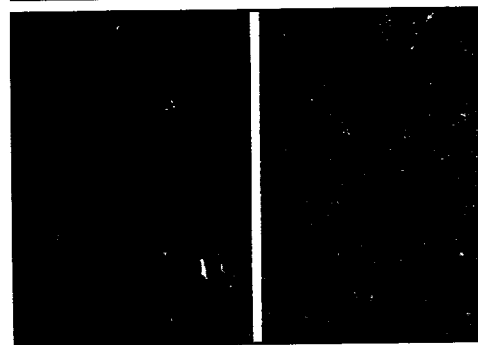
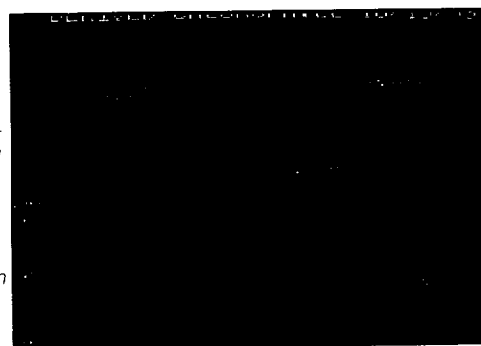


The Biospherics Research Program makes extensive use of NASA technology in satellite-based remote sensing as it examines how the living and non-living components of Planet Earth interact on a global scale.

1. The land cover of Africa. (Yellow = deserts; Green and Red = grasslands and irrigated agriculture; Purple = tropical rain forests)
2. Temperature measurements of the North Atlantic Ocean from Long Island (left) to Nova Scotia (upper right).
3. Distribution of oceanic free-floating plants in the Caribbean Sea as determined from chlorophyll light absorption.



4. Two images of the Washington, D.C. area as viewed by different remote sensing instruments in the infrared band. Note the marked improvement in resolution of the image to the right, a direct result of instrumentation refinements.



ORIGINAL PAGE
COLOR PHOTOGRAPH

Monitoring Disease From Space

Worldwide, more than 250 million people suffer from malaria. This vector-borne disease may be responsible for more deaths than any other, and the World Health Organization reports that the global malaria situation has deteriorated over the past 15 years.

NASA has, with the assistance of world health agencies, designed a phased multi-year research program to determine the feasibility of using remote sensing and related data-handling technologies to identify, monitor and model the relationship between malaria and its environment.

The initial phase of this research has been implemented in the Sacramento Valley of California. During the summer of 1985, rice fields throughout the valley were examined at regular intervals. These fields were surveyed for two species of mosquitoes along with possible association of aquatic vegetation. Simultaneously, 11 imaging missions were flown by U-2 aircraft to coincide with ground examination of the rice fields.

The results of this study showed that *Anopheles freeborni*, the western malaria mosquito, appeared to be associated with specific vegetation characteristics of rice fields, and that the abundance of larvae showed a significant correlation with reflectance data acquired from the U-2 aircraft. The spectral data showed that those fields with low numbers of mosquito larvae had tended to develop slower than those that had high mosquito abundance. This suggested that vegetation characteristics, identified and tracked with aircraft or satellite-borne sensors during early season rice development, could be used to predict larval mosquito populations in late summer.

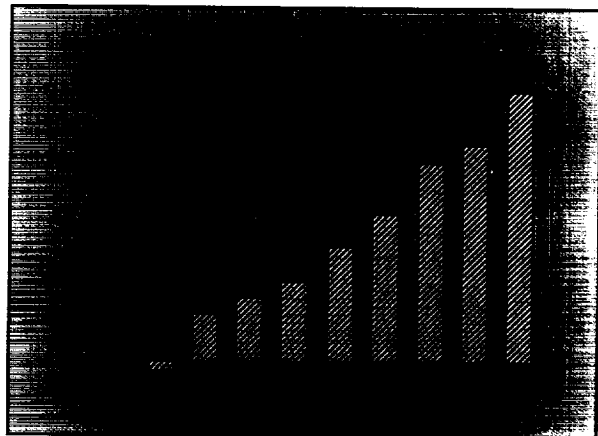
Because of these encouraging results, an expanded study consisting of a more extended monitoring system is being carried out in 1987. The present study will provide an opportunity to better define the functional relationship between the remote sensing data and development of the vector mosquito habitat, and if successful, will offer a more precise basis to work out strategies for controlling anopheline vectors of malaria in afflicted areas of the world.



Earthly Benefits from Space Research

According to estimates by the World Health Organization, almost half the world's population lives in areas where malaria now exists, and another 18 percent in areas where it could exist. Nearly 100 million new cases are reported annually, and the numbers are increasing as populations shift, vaccines prove ineffective and malarial mosquitoes become resistant to pesticides. The disease is not confined to remote tropical areas; a recent outbreak in San Diego had 32 reported cases.

For these reasons, NASA researchers plan to work with the World Health Organization to determine if it is feasible to predict mosquito breeding cycles and locations from remotely sensed imagery. If reliable correlations are made between remotely sensed environmental factors and the growth of mosquito populations, this knowledge could be used to classify breeding areas by high or low yield, and to attack the problem before mosquito larvae turn into carriers of malarial parasites and other disease agents.





The tropical rain forests of Costa Rica serve as outdoor laboratories for NASA scientists studying the nitrogen cycle. Nitrogen, in its nitrate and other "soil-fixed" forms, is an essential nutrient for plants, but distribution and utilization vary widely. The cycles of nitrogen and other nutrients and gases in tropical rain forests are being determined; losses of major tracts of the world's rain forests may upset these delicately balanced cycles on a global scale.

Gas Production of Tropical Forests

Understanding the cycling of trace gases in the atmosphere is important in predicting climate change and the impact humans have on the biosphere. Nitrous oxide, for example, is produced naturally in forest soils, but also enters the atmosphere through the use of fertilizers and the fuel combustion of automobiles. Because it can destroy ozone and contribute to the "greenhouse effect," the nitrous oxide balance is of concern to global habitability researchers.

One key question that remains unanswered is where the nitrous oxide goes. There appears to be a shortage of "sinks" to remove the gas from the atmosphere, since global levels are steadily rising. Recent research has identified a

potential new sink: the desert. This work indicates that the thermal and chemical characteristics of desert soils can break down nitrous oxide into other products.

Tropical forests contribute up to 40 percent of the nitrous oxide in the atmosphere, with the Amazon forest alone accounting for as much as 10 percent. But tropical forests are being destroyed or changed at an ever increasing rate by industrial and agricultural practices, and most of the world's population growth is in tropical areas. Will this influence the balance of nitrous oxide in the atmosphere?

As a follow up to an earlier research project conducted during the dry season in 1985, field work for a wet season Amazon Ground Emissions study has been successfully completed. Using collecting chambers placed on the ground to trap gas emissions, field researchers measured the exchange of gases between forest and atmosphere in three different types of woodland in the Amazon. Nitrogen cycling--a key process for all forms of life--was also characterized for the different soils. These measurements are then compared with remote sensing data from airborne infrared sensors, and from Landsat and other satellites. Similar fieldwork has been conducted in forests in Costa Rica and Hawaii.

Not only do nitrous oxide cycles vary according to season and plant fertility, but different forests within the Amazon also show marked variations--as much as a factor of five--in nitrous oxide output. Preliminary results suggest that conversion of forest to pasture significantly alters the cycling of nitrous oxide.

The distribution of another biologically significant gas, methane, also was traced for the Amazon. Field workers surveyed rivers, meadows and marshlands to find variations in the production of methane, which results from the decomposition of organic material. By knowing these variations, atmospheric modelers can refine their figures for global distribution of an important "greenhouse" gas that may affect the Earth's climate.

Remote Sensing of Temperate Forests

Airborne pollution is widespread in the forests of North America and other temperate regions of the world, and in recent years has taken on political as well as ecological significance. Pollutants like ozone, acid rain and acid mist

can have direct and harmful effects on plant foliage, to the point where the chemical composition of leaves can be altered or the plants can drop their leaves prematurely.

Researchers are conducting experiments to determine if these changes due to pollution can be detected using remote sensing techniques. The investigations have shown how leaf cells shrivel and wrinkle in response to pollutants, how the water content of the cells drops, and how these changes affect the way the leaves reflect light. In addition to a change in pigmentation, laboratory work with conifers shows that it is an actual physical change in the internal shapes of the leaf that alters the spectral characteristics of the plant.

Whether these changes can be sensed by airborne (or, ultimately, spaceborne) instruments is being tested in sites well known for such pollution--the Los Angeles air basin and Santa Monica mountains, and the high elevation forests of Sequoia National Park in California.

Researchers also are using remote sensing technology to determine precisely which plant growth indicators can be measured on a continental scale from space. In this continuing program of basic research, remote observations of a large area of forest canopy are matched with ground data on the health of plants and the efficiency with which they use light and nutrients.

Seasonal trends in plant growth over the entire globe can now be monitored using data from advanced satellite instruments. Recent results suggest that fundamental indicators of plant growth, such as the amount of solar

radiation absorbed by the canopy for photosynthesis, are both useful and possible to measure remotely. These studies have so far been done in temperate coniferous forests and in salt marsh wetlands where land and sea meet.

Global Studies

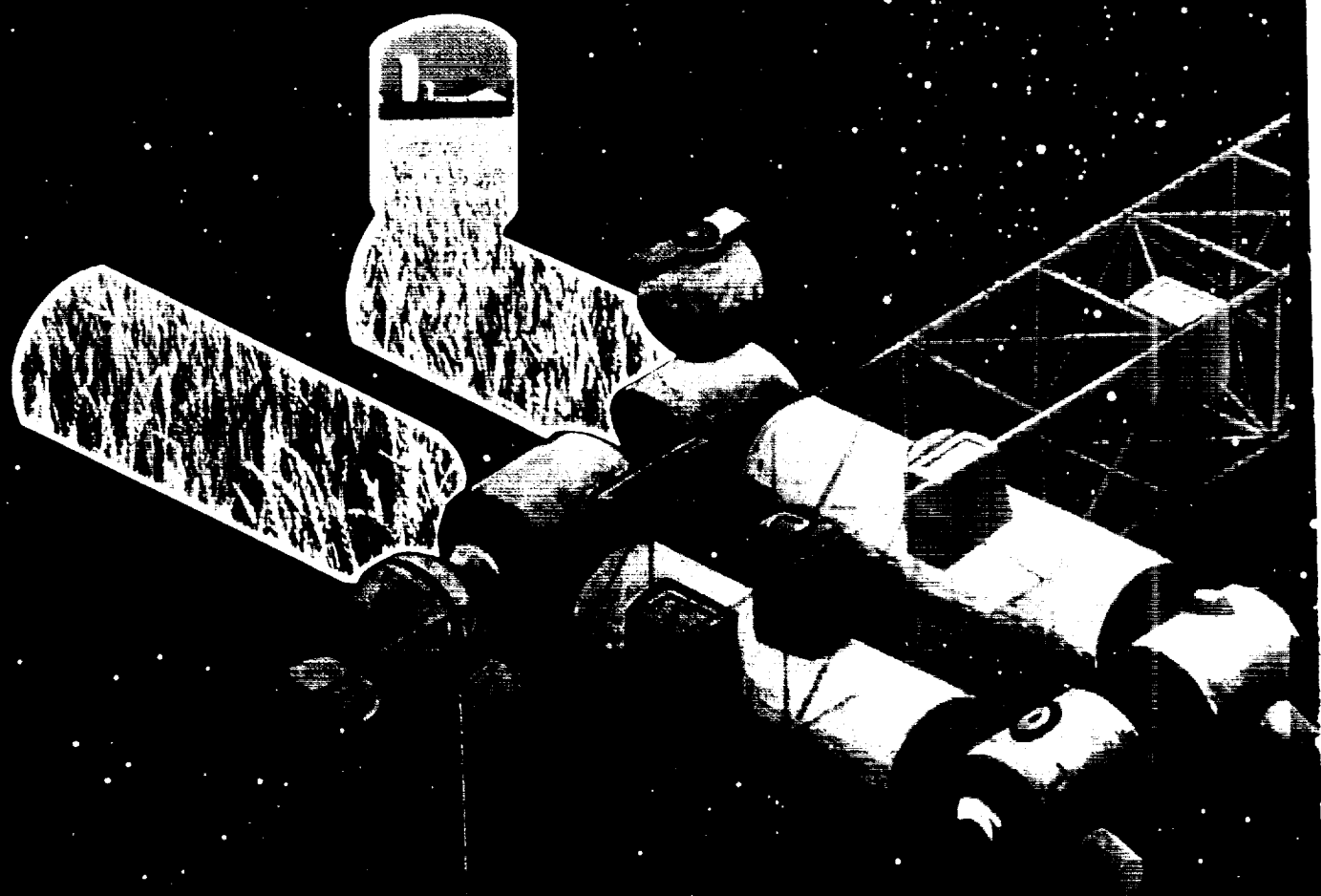
Data collected by satellites and by field researchers can be used, with the help of sophisticated computers, to produce models mapping the concentrations of trace gases in the atmosphere. For example, satellite vegetation maps that show worldwide seasonal changes in green leaf density have been used to index the global distribution of carbon dioxide, which is used by plants in photosynthesis.

Computer modelers are now combining data from wetlands worldwide to map the global distribution of methane in the atmosphere. This geographic information on methane sources will allow more precise assessments of the atmospheric "budget" for this important biological and greenhouse gas.

The great promise of such models, and of remote sensing of the biosphere in general, is that it will reduce the need for expensive field expeditions at the same time as it expands the geographic areas open to scientific observation. By the next century, platforms and space stations in orbit may routinely monitor remote regions that were totally inaccessible in the last century, and that knowledge will be used to draw an integrated picture of planet Earth.



The Earth gleams brightly against the stark, black backdrop of space. The United States and other parts of North America are clearly visible in this photograph taken by the Apollo 16 astronauts.



CELSS: Supplying Humans in Space

Certain basic physiological needs must be met in order for human beings to stay alive. On Earth, these needs are met by other life forms in conjunction with geochemical processes that effectively use human waste products in conjunction with energy from the Sun to produce fresh supplies of food, oxygen and clean water. In the artificial environment of a spacecraft, these materials must be provided, and human wastes removed, without relying on the natural resources of the Earth's biosphere.

To date, space missions have used a simple "open" system, bringing along all necessary sustenance for the crew and venting waste products to space or collecting and storing them for return to Earth. As missions become longer and crews increase in number, however, it is apparent that storing or resupplying consumables would at some point become expensive, and eventually prohibitive in cost. The NASA Controlled Ecological Life Support System (CELSS) was initiated as a long-term research and development effort to fulfill a future need for recycling and regenerating materials for human consumption during extended space missions. This recycling of material is referred to as a "closed" system. The CELSS program has been directed primarily toward combining biological and physical-chemical systems for regenerating air, water and food from wastes.

Trying to recreate the cycles of nature in a relatively small chamber is a great technical challenge. Plants "breathe" carbon dioxide and "exhale" oxygen, so in a broad sense human wastes are used by plants, and vice versa. But in nature the nutrients, air, water and energy are freely available. In a CELSS system all of these elements must be imported and carefully managed in a closed cycle.

NASA's Life Sciences Division is now actively conducting research both in the engineering of hardware for a CELSS system and in the growth of edible biomass in controlled environments. Part of this applied CELSS work overlaps more fundamental gravitational biology studies of how plants behave in weightlessness.

The CELSS Breadboard Project

A Plant Growth Chamber at the Kennedy Space Center in Florida is being used as a prototype facility to learn the technology requirements for a CELSS module in space.

The 80 cubic-meter chamber has 64 trays available for growing hydroponic crops. Gases, water and nutrients are piped in from closed tanks attached to the chamber, and such factors as temperature, airflow, humidity and carbon dioxide levels can be controlled. Illumination is provided by lamps, which achieve about 50 percent of full sunlight.

The steel chamber can be sealed so that the plant growth system is completely closed. Air and water are cycled continuously. Water vapor transpired by plants can either be returned to the nutrient solution or removed. In an operational system it might also be converted to drinking water for the crew.

Current engineering studies focus on specific problems of controlling the chamber's environment: how, for example, oxygen and carbon dioxide concentrations and air flow can be regulated, or how waste heat from lamps can be removed from the system and contaminants filtered from the air.

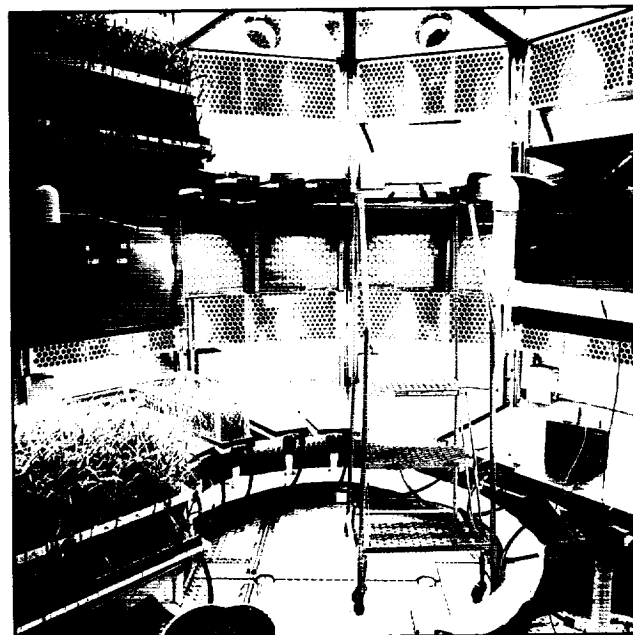
Hardware development also continues. A tubular plant growth system has been developed, which is used to anchor the roots of plants and supply them with nutrients through a porous membrane. Initial trials with this system show that wheat can be grown at a better rate than in the field, with a seed yield comparable to other hydroponic systems.

Phase one of the breadboard project is to demonstrate biomass production in a closed chamber at levels required for a CELSS system. Later phases will include food processing from plant biomass and waste recycling.

Crops were planted in the CELSS plant growth chamber for the first time in December 1986. A full generation of wheat plants grew from seed to mature plants under controlled conditions, and were harvested. Future experiments will grow multiple generations by planting seeds produced in the chamber.

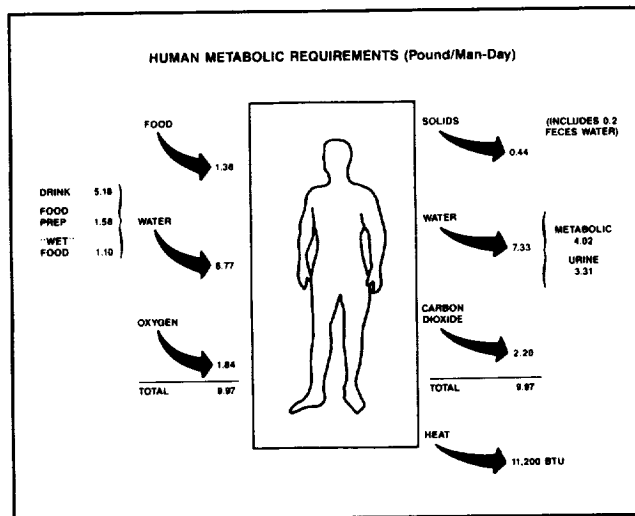


CELSS: Exterior view of the Biomass Production Chamber during its construction.



Wheat grown in hydroponic trays in the top compartment of the Biomass Production Chamber. Note different stages of growth and plant development from tray to tray.

A working CELSS system would likely have different types of plants, and possibly animals, providing a nutritionally balanced diet to a human crew. Potatoes, for example, supply carbohydrate, while soybeans provide protein and fat. CELSS researchers are therefore interested in studying more than one species in the plant growth chamber: in the past year Irish potato, sweet potato and soybean crops were all tested and grown successfully in chambers.



This diagram illustrates daily through-put in pounds of material for the average adult human being. Water and nutrients from solids will be recycled, oxygen will be liberated from carbon dioxide, and the body's heat from metabolism must be dissipated.

Plant Growth for CELSS

As researchers explore ways to make current CELSS crops grow in controlled chambers, they are looking at other candidate species for regenerative life support systems. "New" candidates include oilseed crops (peanut, safflower and rapeseed) and low-fat protein crops (cowpea, snap/dry bean and sugar/shell pea). These candidates were all tested for their growth and flowering responses to different lengths of illumination. Later studies will assess their ability to produce food in a CELSS growth chamber.

Because volume, weight and energy are all at a premium on a closed spacecraft, a particular crop's desirability for CELSS is judged partly on the basis of how much edible food can be continually produced in a given amount of volume, and the amount of light, nutrients and growing time it requires.

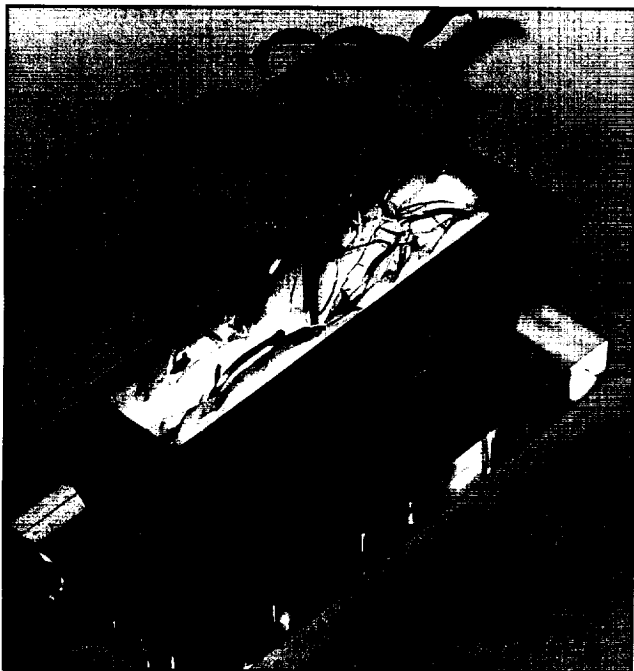
To achieve maximum yields of wheat plants for use in a CELSS system, researchers manipulate such factors as irradiance and length of illumination, temperature, carbon dioxide levels, nutrient flow and humidity for

various types of wheat. These studies in the last year resulted in a tripling of wheat crop yields for CELSS, which is almost four times the world record for field agriculture. The harvest index for these crops (the ratio of edible material to total biomass) is approximately 45%.

The investigations showed that the highest yields came from wheat grown at enriched carbon dioxide concentrations and cool temperatures. The best light-dark schedule was 20 hours equivalent to full summer sunlight and four hours of darkness. Under these growing conditions, combined with high planting densities, a working CELSS system could provide a continual harvest of enough food for a spaceflight crew in only 12 square meters per person.

Similar efficiency studies have been done for potatoes. The major controlling factor for potato production had previously been found to be temperature, with cooler temperatures resulting in higher yields. Like wheat, the potatoes grow better in enriched carbon dioxide levels, while low humidity decreases yield.

Some varieties of potato also increase production as light levels are increased. For example, the "Denali" developed in Alaska under long daylight conditions has been shown to have higher productivity under continuous light in a growth chamber. This would be



Mung bean seedlings grown on STS-3 with an artificial light source.



The disassembled tubular membrane unit of a CELSS experimental system with wheat crop. Of special note is the distribution of the root system around the internal membrane.

Earthly Benefits from Space Research

One of the practical benefits of designing agricultural systems for use in space is that it could contribute to developing new intensive farming practices in extreme environments on Earth. Researchers at Utah State University, working on contract to NASA, have achieved unprecedented harvest yields for wheat plants grown under very carefully manipulated conditions.

Although some of their techniques, such as enriching the carbon dioxide in the atmosphere, may not apply in the open field, the basic knowledge gained from this applied research is of great value. For example, the best strains of wheat for CELSS applications have short shoots, and CELSS researchers are now breeding "ultra-dwarf" strains that produce large seed heads and therefore high yields. Dwarf wheat plants have not been widely planted in the field for various reasons, including poor competition with weeds, but the CELSS research may lead to new insights into how they could be used.

The protein content of CELSS-grown wheat is also consistently 50 percent higher than in the field, which may be due to high concentrations of nitrogen used in the controlled growing process. Once this hypothesis is tested in CELSS chambers, field agriculturalists could conduct similar studies.

The design of small, efficient plant growth chambers may also have practical value in urban areas, in regions where growing conditions are not right for a particular crop, or in extreme environments such as the Antarctic or deserts. And, aside from its importance in food production, CELSS research may provide a model of other closed environments such as modern insulated houses, where plants could act as natural "scrubbers" to remove air pollutants.

valuable in a CELSS system in space, where the period of illumination could be increased to boost crop yields. These studies also evaluate the effectiveness of different kinds of lamps for a CELSS design: high pressure sodium lamps and cool white fluorescent lamps, for example, have been shown to foster similar levels of growth of potatoes.

Other research concentrates on the details of how plants use nutrients: exactly what they need and when they need it. Recent studies have shown that the uptake rate of nitrate (a biologically useful form of nitrogen) by soybean roots is not constant over time, and shows oscillations depending on the external concentrations of nitrate. The uptake also fluctuates according to leaf emergence rates.

Different plants take up nutrients in different ways. Lettuce nutrient uptake seems to be closely correlated with plant mass, while nutrient uptake in wheat depends partly on the developmental stage of the plant. These findings will result in new techniques of nutrient supply that will be incorporated into a CELSS design.

Along with their studies of higher plants, CELSS investigators are looking at alternative food sources that could be grown in a closed system. Algae, in particular, are well suited to a system that combines both food production and air regeneration, and have a large percentage of their total biomass as edible protein.

Experimenters gathered data on the productivity of green algae cultures when temperature, light intensity and carbon dioxide concentrations were varied. These studies also characterized the protein, fat and carbohydrate content of algae for consideration as food sources. A kilogram of paste from algae grown under lab conditions was produced for food

processing studies that explore ways to use more of the available biomass as food.

Experiments with blue-green algae also have shown that when the algae are "stressed" --when salinity is increased and the culture is subjected to cold shock--the relative ratios of carbohydrate, protein and fat become close to those required in the human diet. This suggests that the growing environment of an algal culture could be manipulated to make it a viable food source for a CELSS system.

Although most CELSS crops to date have been chosen for their high ratio of edible food to total biomass, researchers continue to explore methods of converting non-edible biomass to food (candidate techniques include microbial, chemical and enzymatic processes). Research also continues in the technology of recycling biological waste.

One of the best applications of a bioregenerative CELSS system could be at a base on the Moon or Mars, where crops could possibly be grown in native soil, although both lunar and Martian soils would have to be supplemented with nutrients and minerals for plants to grow. Preliminary studies are underway at the Johnson Space Center using simulated lunar soils to examine their basic physical properties and determine their usefulness as a growth medium for plants.

Experiments have also been conducted at the Ames Research Center to grow wheat in a simulated Martian atmosphere supplemented with oxygen. Given enough oxygen, these plants showed a 70 percent germination rate and grew at 30 percent the rate of normal Earth control plants--exciting preliminary results that could prepare the way for CELSS operations on a future Mars base.

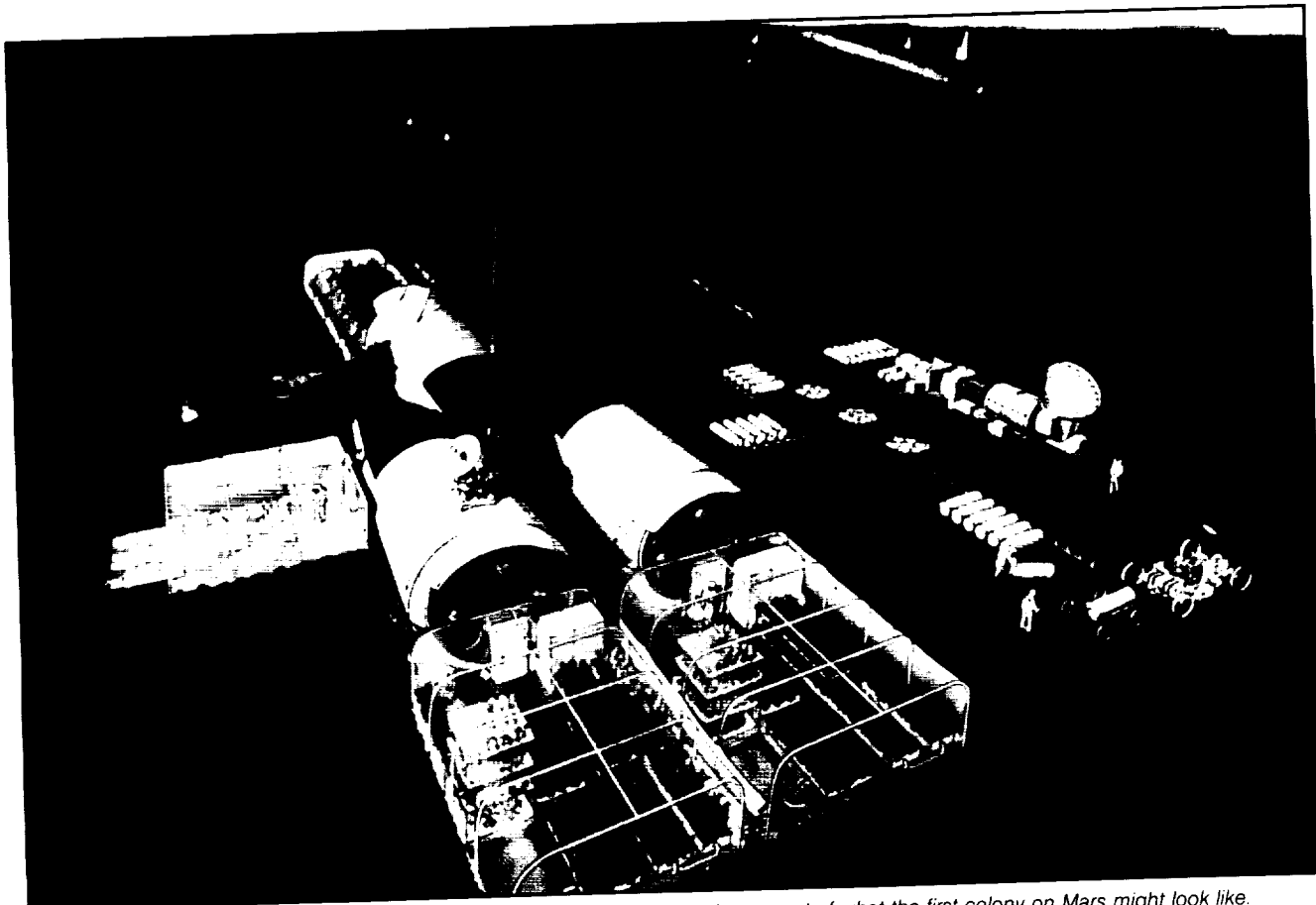
FOLDOUT FRAME

1.



FOLDOUT FRAME 2.





Artist: Carter Emmart

Artist's concept of what the first colony on Mars might look like. Stylized greenhouses such as these might not be practical but food production facilities would be essential to sustain voyages to and permanent human presence on Mars.

ORIGINAL PAGE
COLOR PHOTOGRAPH

Exobiology: Life in the Universe

There are, by even the most conservative estimates, at least 100 billion stars in our own Milky Way galaxy, which is in turn only one of many billions of galaxies in the universe. We know for certain that life evolved around one of these stars--our Sun. Is the Sun unique, or has life evolved in other parts of the galaxy?

Although no planets have been confirmed to exist beyond our solar system, current theories of star formation suggest that many other stars are likely to have developed planetary systems. Scientists also know that the chemical elements and simple molecular building blocks necessary for synthesizing life--including water--are not unique to Earth. Radio astronomers find them scattered widely throughout the universe, even in clouds of dust between the stars.

These same kinds of clouds condensed more than four and a half billion years ago to form the Sun, Earth and other bodies of the solar system. As the Earth formed, it also developed an atmosphere, and later a hydrosphere. Experiments dating back to the 1950s have shown that when energy is applied to a mixture of molecules identical to what is believed to have been in Earth's primitive atmosphere, amino acids and other simple building blocks of life are created.

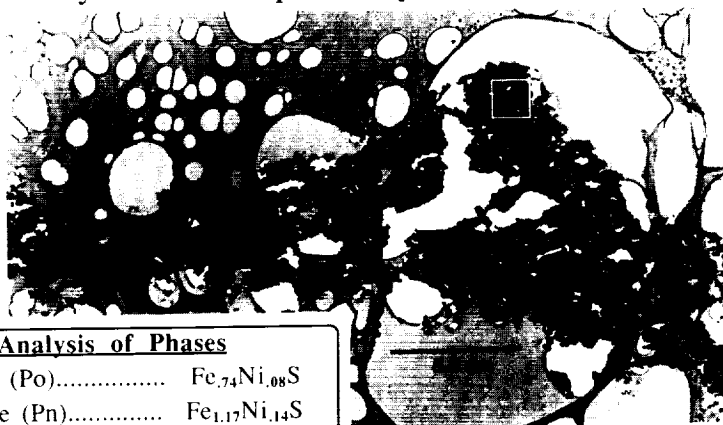
These and other results from astronomy and chemistry suggest that, far from being unique to Earth, life could be abundant in the universe. NASA's exobiology program seeks to understand the nature of that life and the conditions under which it comes into being.

The program's research ranges from studying the most primitive chemical precursors of life to searching for evidence of other intelligent civilizations. One focus is on understanding the physical and chemical dividing lines between the nonbiological and biological worlds--how the structures and functions associated with amino acids, proteins and DNA form from simpler molecules and minerals. Other researchers study the distribution of elements and compounds necessary to life--water, carbon and nitrogen, for example--in cosmic dust, asteroids, comets, other planets and their moons, which tells them whether the chemical conditions are right for life to develop beyond Earth.

The early history of Earth and other Earthlike planets, particularly Mars, is another subject of great interest to exobiologists. What were atmospheric conditions like on primitive Earth, before life developed? How does that compare to other planets, either today or as they were in their past? What led to the origin of life on Earth and its subsequent evolution, and could it have happened elsewhere? What circumstances are absolutely necessary for life to develop on a planet?

Finally, exobiologists intend to search for direct evidence of life beyond Earth, whether in the form of primitive fossils that could be trapped in ancient Martian lake beds or radio signals that could be coming from another technological civilization like our own, circling some other star. These studies will address an ancient and profound question: are we alone in the universe?

Hydrated Interplanetary Dust Particle



Analysis of Phases

Pyrrhotite (Po)..... $\text{Fe}_{74}\text{Ni}_{108}\text{S}$
 Pentlandite (Pn)..... $\text{Fe}_{117}\text{Ni}_{14}\text{S}$

	Smectite (SG)	Smectite (SM)
MgO.....	5.9%	8.5%
Al_2O_3	6.1	5.3
SiO_2	47.2	47.9
FeO.....	20.6	18.3



Interplanetary dust particles, an important class of extraterrestrial materials, are collected in the stratosphere by high-altitude aircraft. Photomicrography and microanalysis of these hydrated particles provide strong evidence of liquid water being present in primitive solar system material. The activity of liquid water is considered to have been essential for the chemical evolution processes leading to the origin of life, so implications of this finding may be far-reaching.

The Chemical Ingredients of Life

It is now well established that stars and planets form in dense interstellar clouds of gas and dust. Gravitation and other forces cause the cloud to contract into a protosolar nebula, from which a stable star is formed. At the end of its lifetime a massive star explodes, and in that explosion the heavier elements of nature—including the carbon on which terrestrial life is based—are created and returned to the interstellar medium, where they undergo further reactions to form compounds.

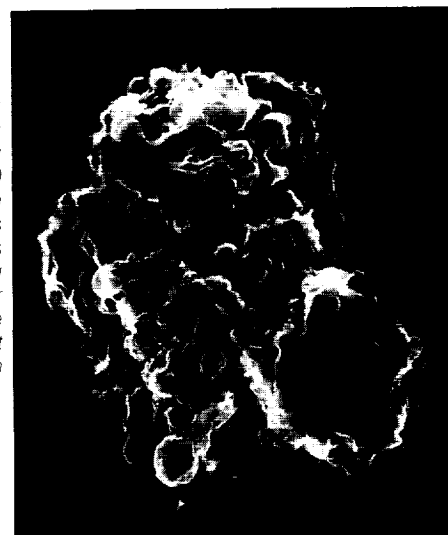
Approximately 70 molecular species, the vast majority of them organic (containing carbon bonded with hydrogen), have been identified in molecular clouds. Recent radio astronomy observations have detected the first phosphorus molecules found in such a cloud. Phosphorus is necessary for the development of amino acids, and with this discovery, all of the "biogenic" elements required for life—sulfur, carbon, hydrogen, nitrogen, phosphorus and oxygen—have been detected in interstellar clouds.

Meteorites are valuable to exobiologists in that they represent the primary source of extraterrestrial material for study on Earth. Carbonaceous chondrites, a particular class of

meteorite, are believed to consist of materials that have gone relatively unchanged with respect to elemental composition since the earliest days of the solar nebula. Recent analysis of amino acids and other organic compounds in carbonaceous chondrites indicates that they or their precursors existed in the interstellar medium even before the solar system formed.

Interplanetary dust particles, another important class of extraterrestrial material, are

Electron micrograph of an interplanetary dust particle, 10 microns in diameter. This particle was collected during NASA's Upper Atmosphere Cosmic Dust Collection Program.



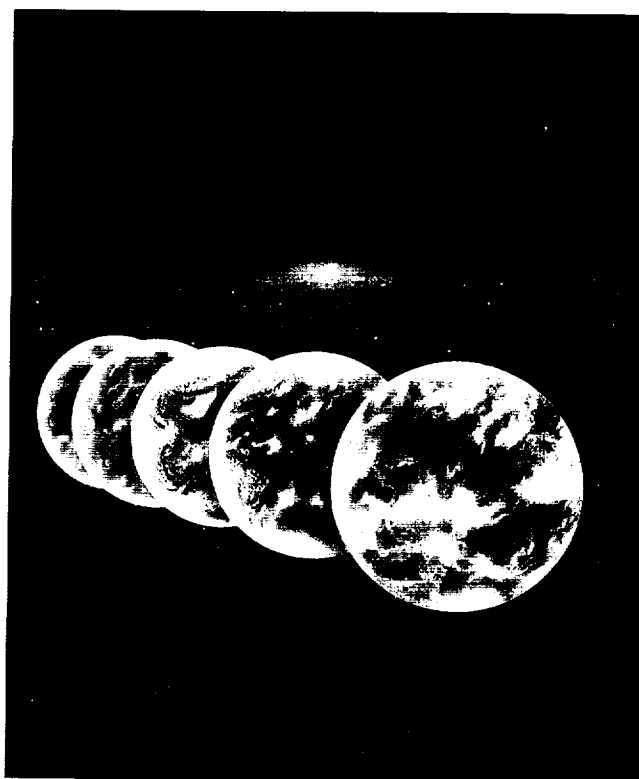
collected by high-flying aircraft in the stratosphere. Many of these grains are thought to originate in comets and asteroids, and so may date back to the earliest days of the solar system. Using a new technique, researchers have been able to slice extremely thin sections of dust particles for chemical and microscopic analysis. These studies provide strong evidence that the dust particles were once part of a larger body in which liquid water--life's most essential ingredient--was present, and in some cases water can be measured in the particles.

As relics from the early solar system, comets are of great interest to exobiologists. Life scientists are now preparing a Cometary Ice and Dust Experiment (CIDEX) for inclusion on the Comet Rendezvous/Asteroid Flyby (CRAF) mission scheduled for the 1990s. CRAF will match orbits and fly along with a comet, providing CIDEX and other experiments with the first chance to make a thorough study of the abundance of biologically important elements in a comet.

The Origin and Evolution of Life

The early atmosphere of Earth almost certainly played a key role in the formation of life, but it was free of oxygen and much different from the atmosphere that exists today, which has resulted from extensive changes wrought by photosynthetic and other types of organisms. Exobiologists therefore seek to understand the chemical composition of the early atmosphere before life appeared more than 3.5 billion years ago. One open question is what role chemically reduced iron, which reacts in the ocean with oxygen, played in limiting the influence of oxygen at the surface and at depth. Another question is what role was played by the interaction of sunlight with water vapor in producing oxygen and ozone in the atmosphere and at the Earth's surface.

Nitrogen is another atmospheric constituent essential to life. Nitrogen in the atmosphere must first be "fixed"--converted into a form useful to other organisms--by natural abiotic processes or by bacteria. Therefore, the question of how nitrogen was first fixed by living systems is important to understanding the origin of life. Mars is believed to have had much lower nitrogen pressures in its primitive atmosphere than what we see on Earth today. Recent experiments have shown that bacteria are still

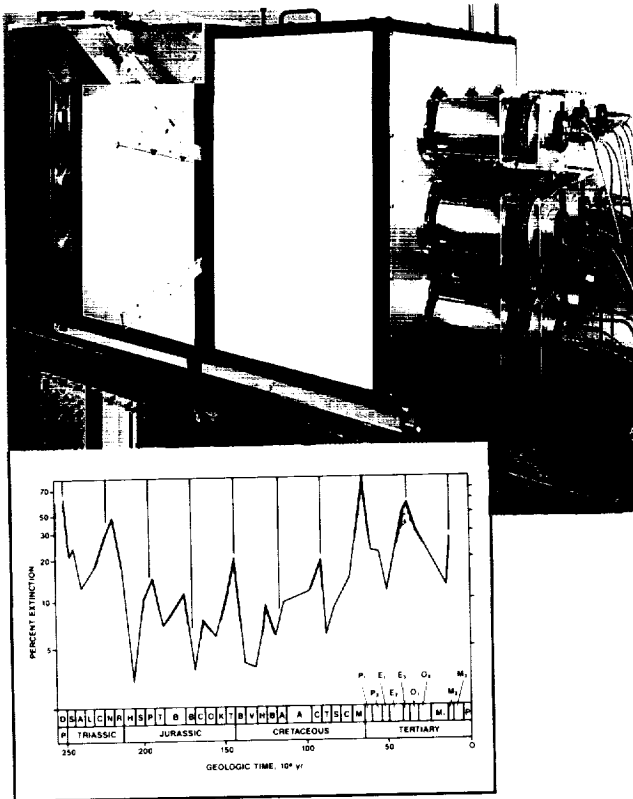


*Throughout the eons, geologic and evolutionary forces have changed the face of our Earth. The timecourse of four billion years of planetary change and evolution is depicted here.
Artist: Jon Lomberg*

able to fix nitrogen even at these low pressures, indicating that this alone would not have deterred the formation of primitive life on Mars.

In order to understand how the first living organisms arose, exobiologists must also discover how complex molecules such as nucleic acids and proteins--which allow biochemical reactions to take place--were formed during the "prebiotic" era. One proposal is that polymers made up of the building blocks of nucleic acids acted as templates that directed the synthesis of other so-called complementary polymers based on the templates' affinity for the simple complementary "building blocks." Some theorists suggest that clay minerals may have acted as templates for primitive life, and recent findings that clays can catalyze the formation of the biologically important phosphate ester bond lend experimental support to this theory.

One of the essential steps in the evolution of life was the formation of membranes that could act as barriers between biological material and the outside environment. Recent experiments show that even the primitive organic



Lawrence Berkeley Laboratory's new Iridium Coincidence Spectrometer combines great sensitivity and speed in searching the geologic record for evidence of extraterrestrial impacts. One hundred times faster than conventional techniques, this dedicated Spectrometer detects iridium in geologic samples. Anomalously high concentrations of iridium found in geologic formations of similar ages at regular intervals of 27-1/2 million years has resulted in the hypothesis that periodic impacts of major comets or asteroids may have been responsible for the massive biological extinctions throughout our planet's history.

components in meteorites have the capacity to self-assemble into structures resembling membranes. These meteoritic organic substances would have been available in the environment of the prebiotic Earth. Using computer simulations, scientists at the Ames Research Center are now trying to model the transport of ions across membranes to better understand these most basic biological processes.

ATP (adenosine triphosphate) is the universal energy currency of cells, which are the basic building blocks of all forms of life. In certain primitive bacteria ATP is synthesized by an enzyme called ATP Synthase, and research into the structure of this enzyme has established that it is composed of four subunits. Recent analyses have shown that one of these subunits shares certain properties with an analogous

subunit found in the ATP synthase of other life forms. This suggests a common origin, and may lead to new understanding of the origin of the enzyme that synthesizes ATP, which is essential for almost all life as we know it.

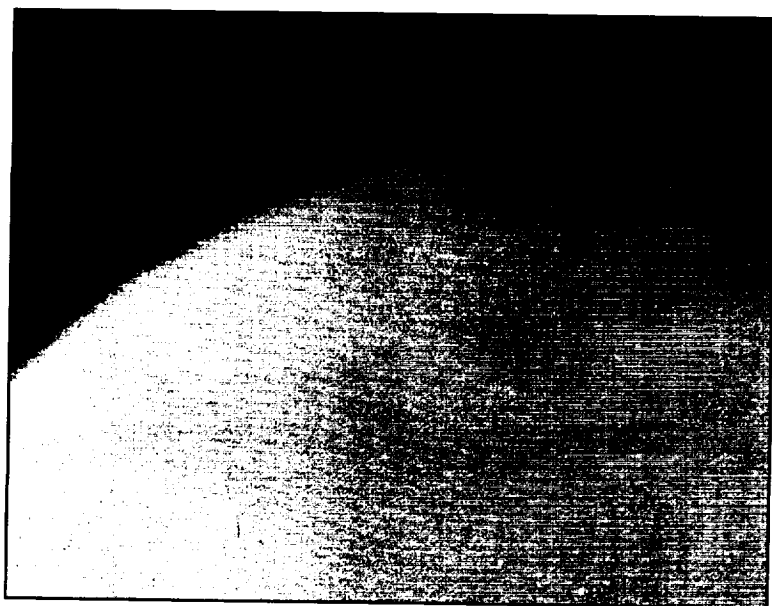
Since the late 1970s, geologists and paleontologists have collected evidence from widely scattered parts of the world that links major extinction events, such as the disappearance of the dinosaurs and other species 65 million years ago, to astronomical events--specifically the impact of comets or asteroids. These extinction events may be directly linked to the evolution of advanced life on Earth. NASA pioneered these studies, and has since been joined by the National Science Foundation in sponsoring some of this exciting work. In addition, NASA's Life Sciences Division, along with the Department of Energy, has recently supported the development of a new spectrometer sensitive to iridium, allowing one of the key signatures of meteorite impact to be measured in samples from all parts of the globe.

Biology in the Solar System

The only planet where we know for certain that life exists is Earth. Robot spacecraft have now visited or flown by all but two of the other eight planets of the solar system, and have found no clear signs of biological activity.



Montage of individual images received from Voyagers 1 and 2 during their Saturn encounters. Titan, the largest of 17 known Saturnian satellites, maintains a massive atmosphere.



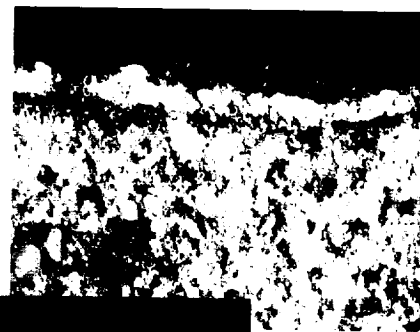
Titan's thick haze layer is shown in this enhanced image from Voyager 1. Instruments detected an atmosphere containing organic compounds, and which is possibly denser than that of the Earth's.

Nonetheless, conditions suitable to the origin of life may exist elsewhere in the solar system. Organic compounds have been detected in comets and meteorites and on at least three large planetary satellites--Saturn's Titan, Pluto's Charon and Neptune's Triton. Water is abundant in the solar system as well. Mars almost certainly had water running on its surface in the past, and now may have water ice trapped beneath its surface. Planetologists also believe that beneath the cracked, icy surface of Jupiter's moon Europa may be an ocean of liquid water, which is essential for life as we know it.

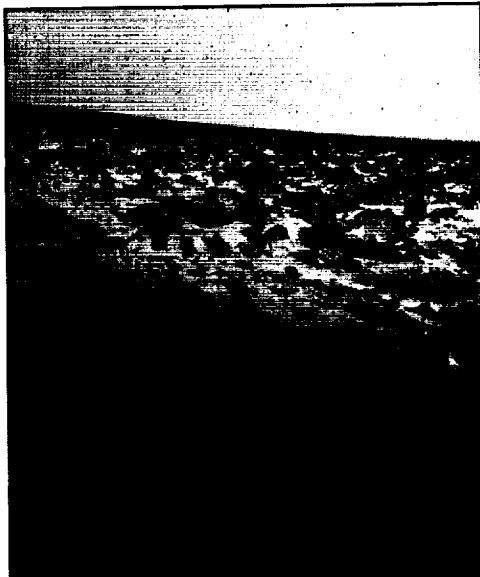
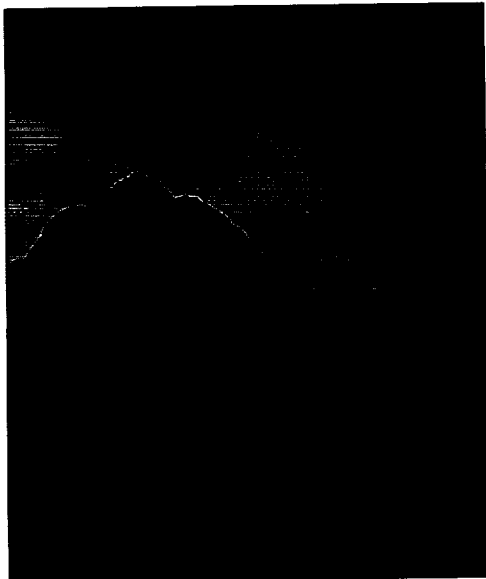
Saturn's moon Titan is a particularly interesting object, with its thick atmosphere hiding a surface that is likely to contain complex organic compounds. A highly miniaturized gas chromatograph has been developed for the chemical analysis of Titan's atmosphere, to be included on a Titan probe mission in the 1990s. In the meantime, experimenters are conducting laboratory studies in order to focus their future analysis. In these laboratory tests electrical sparks are introduced to a simulated Titan atmosphere to see what chemical reactions take place and what byproducts could develop on Titan itself.

Exobiologists have long been interested in studying the cold deserts of Antarctica as an analog to the hostile surface of Mars. Recent research has focused on permanently frozen Antarctic lakes that have liquid water under a permanent layer of ice--conditions that may match those of early Martian lakes. By studying sedimentation processes and microbial carbon and nitrogen cycles in these Antarctic lakes, scientists hope to characterize the types of fossil traces that might have been left by primitive life forms on early Mars.

Photographic detail of cryptoendolithic lichen living within the interstices between quartz grains of fractured sandstone.



Fractured sandstone found in the dry valleys of Antarctica, showing black, white, and green zones of cryptoendolithic lichen living within rock just beneath the surface.



The Antarctic dry valleys, cold, desolate and dry regions free of ice and snow, provide the best terrestrial analog to the surface of Mars (far left). Photograph by Dale T. Andersen.

The surface of Mars (left) bears a striking resemblance to Antarctica's dry valleys. This high-resolution color image by Viking Lander 2 at its Utopia Planitia landing site shows a thin layer (perhaps no more than one-thousandth of an inch thick) of water ice coating the rocks and soil.

The Mars-Antarctica Connection

Did life ever exist on Mars? The Viking landers in the 1970s found a planet that is dry and apparently lifeless today. But ancient river channels seen in photographs of the Martian surface show that there was once running water, and other geologic evidence supports the belief that there is still ice trapped at the poles and in permafrost beneath the surface.

Since water is key to life as we know it, the most likely places to look for fossils of primitive organisms on Mars would be in regions where scientists suspect standing lakes of water existed during an earlier, warmer period. When Mars turned cold these lakes would have formed a crust of ice over the water, which could have remained liquid long after the surface temperatures dropped below freezing.

Such lakes exist on Earth today, in the dry valleys of Antarctica, where low temperatures and the lack of precipitation provide a model of early Mars. Research divers have recently explored these lakes to find cyanobacteria, diatoms and other primitive organisms in dense microbial mats that trap and bind sediments, which over time may form fossils called stromatolites. Close analysis of these sediments, and data on trapped gas and energy cycles within the iced-over lakes, will help scientists know what to look for on a future robotic or human fossil-hunting expedition to the now dry valleys of Mars.

Scientist prepares for a dive to the bottom of this Antarctic lake. The dive hole penetrates five meters of ice before reaching the body of water underneath.



Microbial mat living at the bottom of an Antarctic lake. These lakes are perennially frozen over with five meters of ice. Photograph by Dale T. Andersen

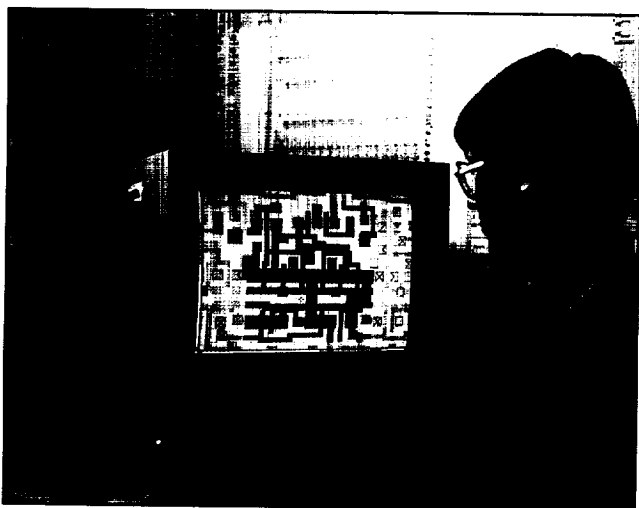


The dry valleys of Antarctica are also home to crypto-endolithic organisms--lichens that live within rocks. Recently, these lichens have been found to leave fossil remains in the rocks in which they have lived. Understanding how these fossils formed could aid in the search for similar fossils during a future mission to Mars. Life scientists are now developing a strategy for exobiological study of Martian sediments, so that when a sample return rover lands on Mars it will know where and how to look for evidence of life.

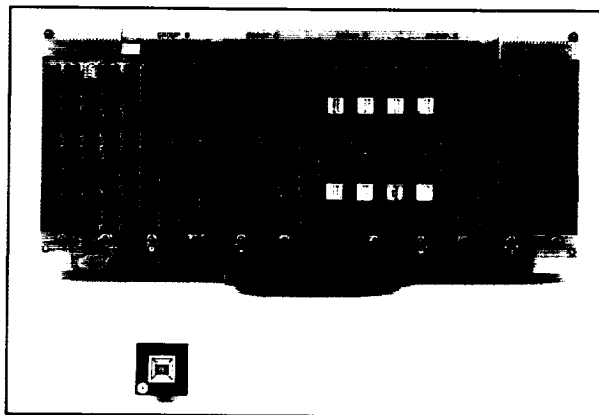
The Search for Extraterrestrial Intelligence

Are there advanced civilizations beyond Earth? The answer has profound implications reaching far outside the field of exobiology. NASA is now ending a five-year research and development program that has established the basic methods and technology needed to begin a comprehensive search.

Astronomers have long agreed that the radio spectrum is the most practical and affordable place to begin looking for signs of extraterrestrial technology. Deliberate signals must be distinguished from the natural radio "noise" of astronomical objects, so SETI (Search for Extraterrestrial Intelligence) researchers are concentrating their early efforts on the least noisy parts of the spectrum, where a transmitter would need the least power to produce a signal that could be detected.



The DSP chip, developed by a design team at Stanford University, utilized an advanced computer-aided design system. A portion of the chip circuitry is shown on the CRT display.



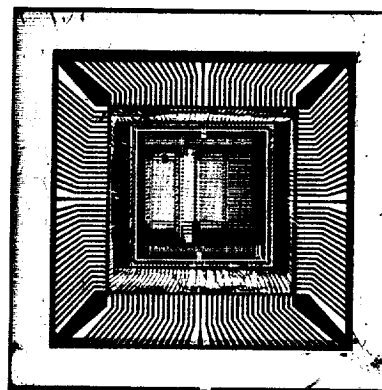
The SETI digital signal processor chip is shown below an integrated circuit board from the Multi-channel Spectrum Analyzer (MCSA). The operational prototype MCSA is already the most sensitive receiver in NASA's Deep Space Network.

Earthly Benefits from Space Research

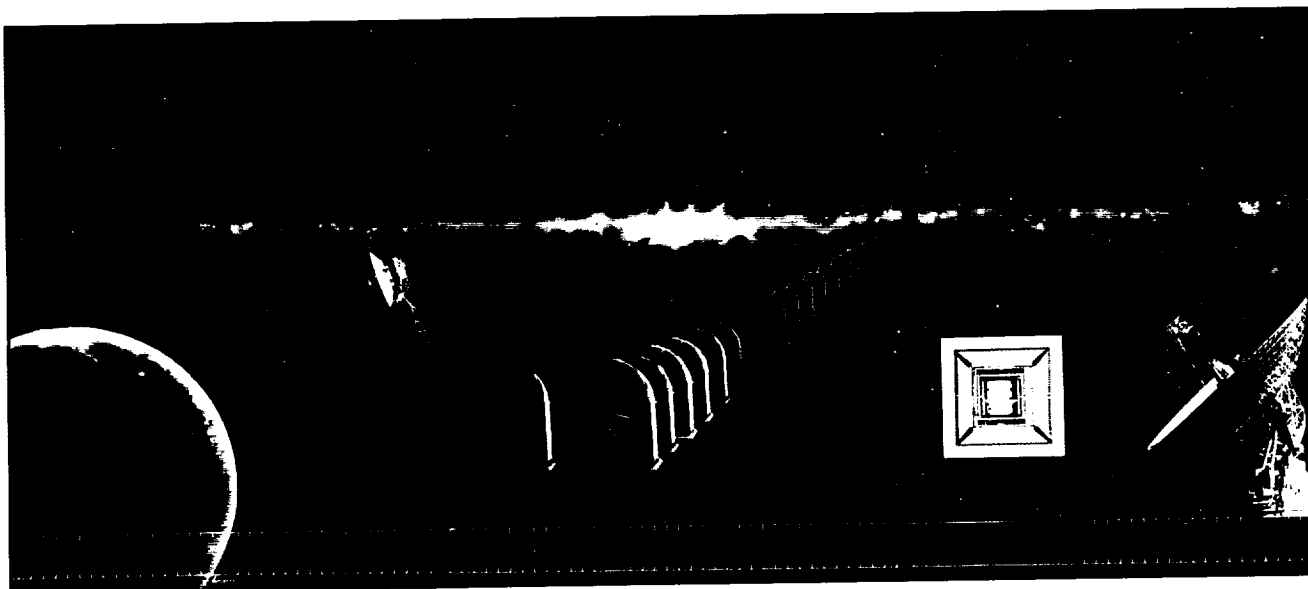
Super-programs and computer chips custom-made for a SETI spectrum analyzer could have applications in many other fields beside the search for extraterrestrial life.

The SETI analyzer requires a digital system that performs on the order of 10 billion operations per second, which exceeds the speed of existing supercomputers. Its high-speed ability to discriminate among many millions of frequencies would find applications in medicine and exploration geology, both of which use high frequency sound waves as diagnostic tools. Doctors and geologists could process ultrasound signals with greater resolution, without having to rely on more costly supercomputers.

Also, the detectors required for a SETI radio search would enhance ongoing astronomy projects, and the low-noise receivers and high-resolution signal processors developed for SETI would be invaluable to radio astronomers working on other problems.



Close-up photograph of the Very Large Scale Integration (VLSI) computer processing chip (center) and connector package. This digital signal processor (DSP) chip, only eight millimeters square, contains the equivalent of 34,000 transistors.



Searching the spectral heavens, scientists garner information on the universe. The SETI program searches in a quiet band in the electromagnetic spectrum (large red band, lower right), "listening" for signals of distant civilizations' technologies. Radio broadcasts, leaking from Earth in all directions, occupy a narrow band of the spectrum (red, center and bottom). Artist: Jon Lomberg.

Recent technology development has combined sensitive receivers with fast, efficient computer circuits and programs that make the vast job of sifting through the noise for patterns much easier. An advanced Very Large Scale Integration (VLSI) computer processing chip has been developed for an operational SETI system able to scan 10 million radio frequencies simultaneously, looking for signal patterns.

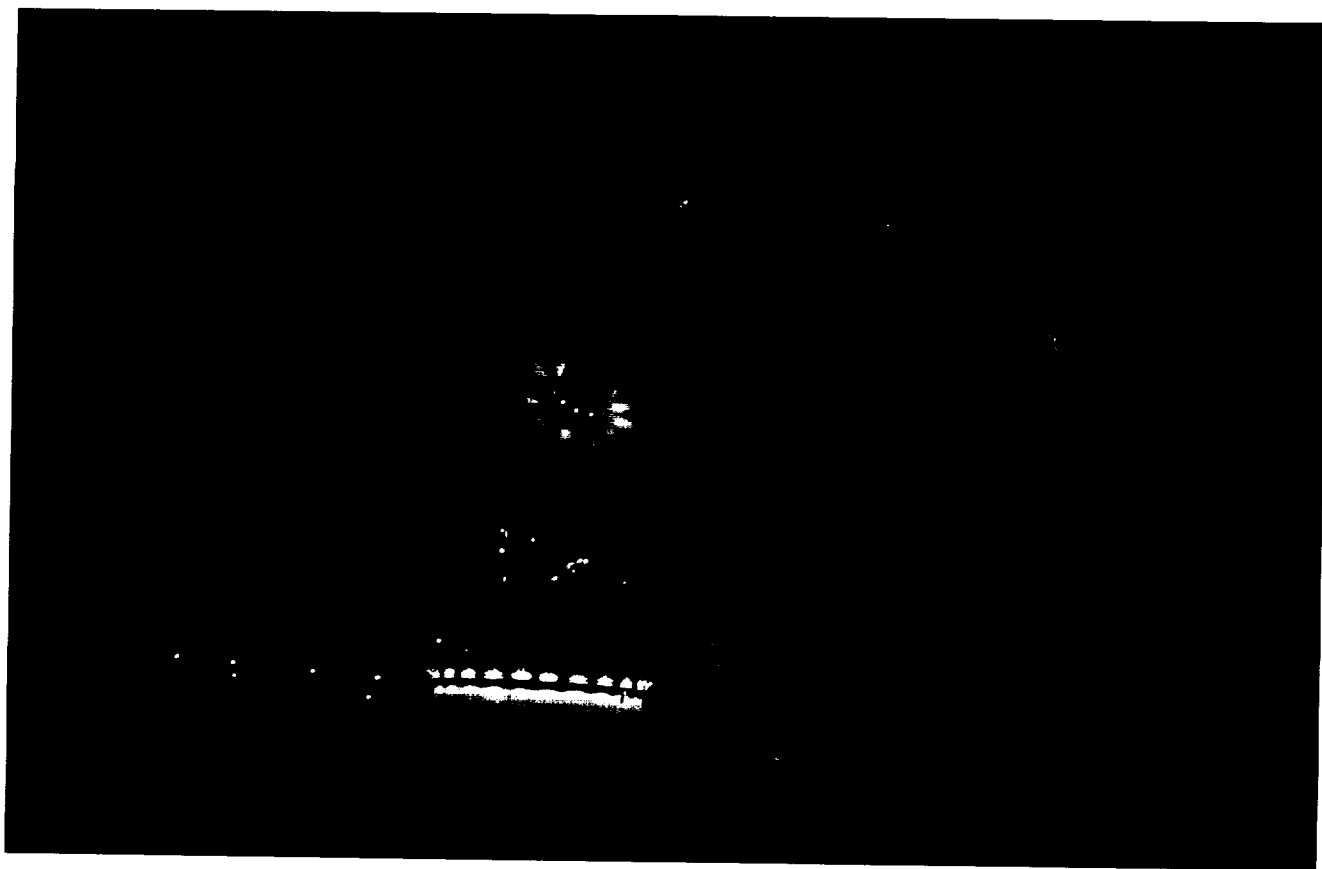
This breakthrough allows for the most comprehensive search to date, exceeding all previous searches by a factor of ten billion. It will be the first to take into account another planet's motion with respect to the Earth, and the first able to recognize drifting or pulsing signals, as opposed to steady, continuous tones.

The proposed Microwave Observing Project would be conducted in two parts: an all-sky survey to cover the entire celestial sphere, and a targeted search to look more intensely for signals from 800 selected nearby solar-type stars.

Using a prototype 74,000 channel version of the signal analyzer to be used in the actual SETI Microwave Observing Project, researchers have tested the system's ability to detect faint signals coming from our own spacecraft scattered throughout the solar system--the only known "intelligent" objects in deep space.

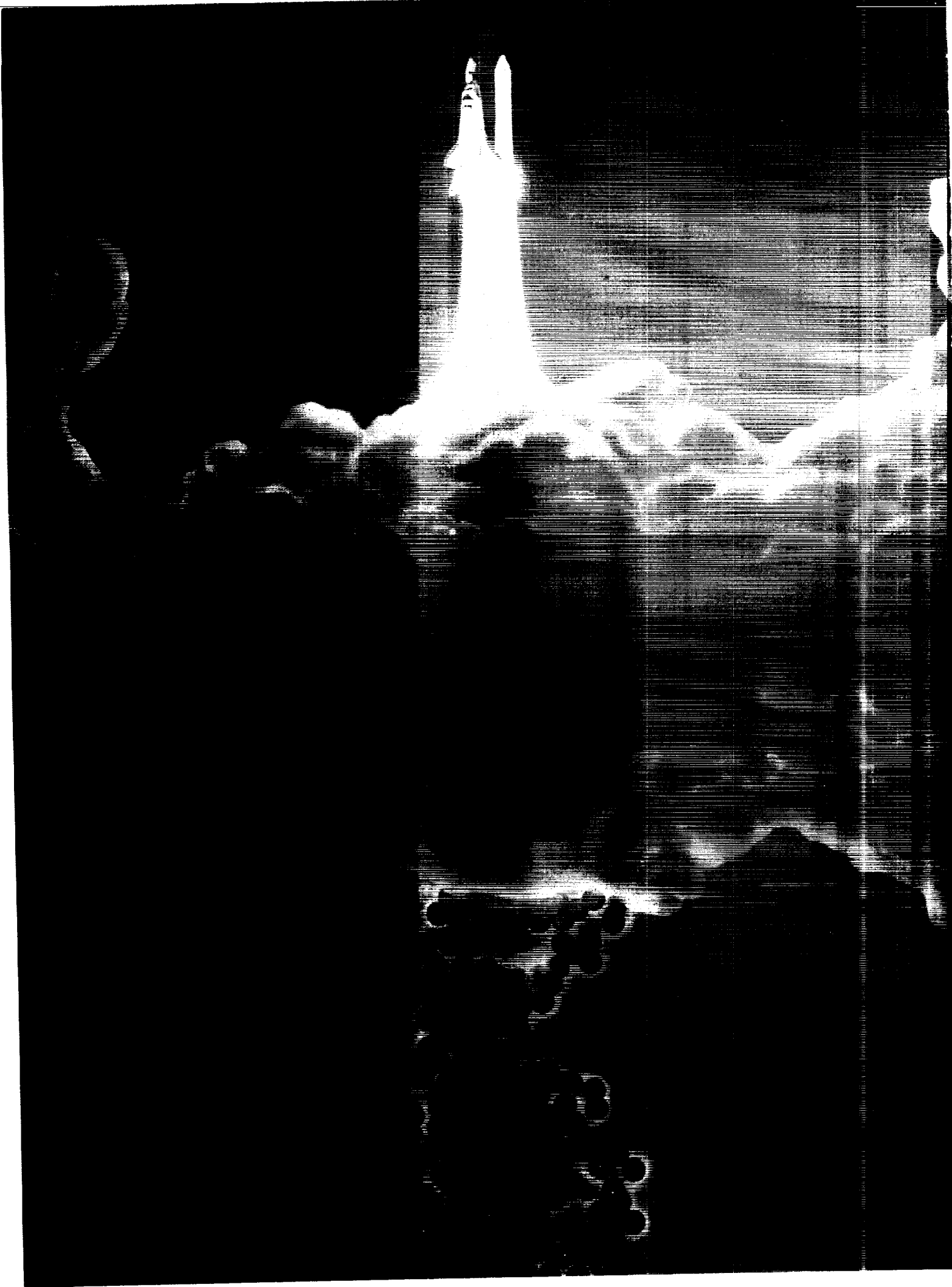
These tests have shown that the system can easily pick out radio signals transmitted with only one watt of power by the Pioneer 10 and 11 spacecraft 4 billion miles from Earth. The detectors and analyzer have also "discovered" signals from the International Cometary Explorer, Voyager 1 and 2, and Pioneer Venus spacecraft.

This confirmed ability to identify artificial signals against a background of radio noise has prepared the way for development of the much more versatile analyzer to be used in the operational search. Meanwhile, terrestrial sources of radio interference are being catalogued for entry in the SETI computer's checklist of possible "false" signals.



The 210-foot diameter Goldstone (CA) tracking antenna is shown reflected in a mirror.

ORIGINAL PAGE
COLOR PHOTOGRAPH



Flight Programs: The Need to Experiment

Although some space life science research can be conducted in laboratories on the ground, there is no substitute for actual in-flight experiments. The Flight Programs Branch of NASA's Life Sciences Division is responsible for conducting experiments in space. As such, it oversees the development of facilities and hardware for spaceflight experiments, manages their integration into mission plans, and sees them through to flight in space and postflight data analysis.

The Flight Programs Branch concentrates on preparing for future missions--maintaining and reworking hardware as well as adding to the existing Life Sciences Laboratory Equipment (LSLE) inventory of more than 40 types of flight-qualified items that can be shared and re-used by many different experimenters.

The major facilities available for in-space experiments are the shuttle's mid-deck and cargo bay, Spacelab, and eventually the Space Station. In addition, NASA life sciences experimenters participate in international missions and work on designing instruments for unmanned solar system probes to perform exobiology experiments.

As part of its new "mixed fleet" policy, NASA is once again turning to expendable launch vehicles--conventional rockets--as a means to place payloads in orbit. The Flight Programs Branch is exploring the feasibility of a recoverable satellite called Lifesat as a means to take advantage of these new launch opportunities. The Lifesat capsule would be placed in orbit for up to sixty days, and would return to Earth using a re-entry heat shield. Inside the small spacecraft would be an experimenter's choice of plants or animals, along with basic life support systems, power, lighting and monitors.

The biosatellite could be launched from either the shuttle or expendable vehicles.

Expendables could carry radiation experiments into polar orbits inaccessible to the shuttle. The Lifesat concept would be an effective bridge between short-duration shuttle flights and the longer missions of the space station era.

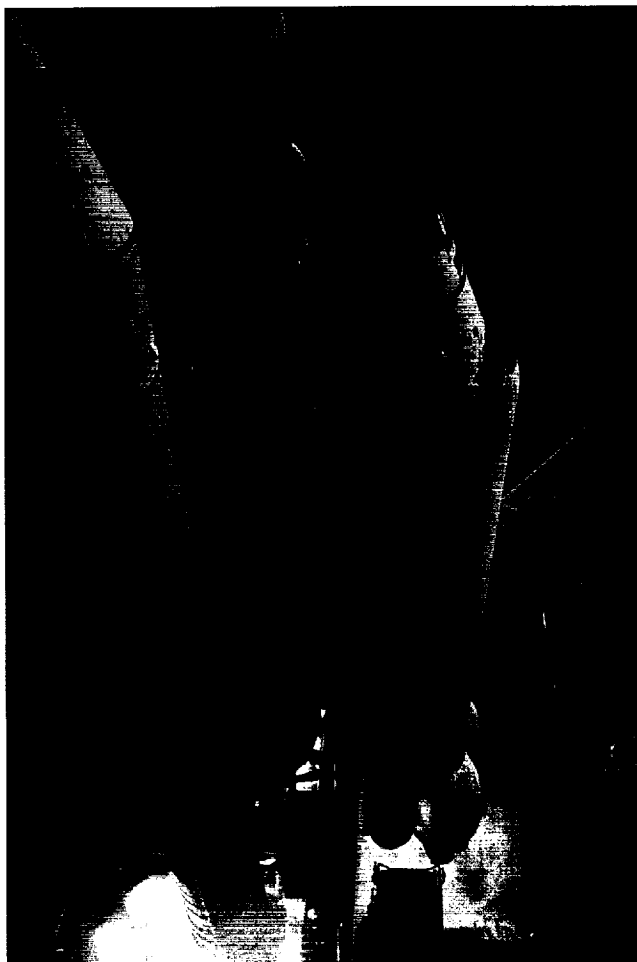
Through these varied means, life scientists gain access to the natural laboratory of space. Flight experiments provide a vital link between empirical observations of life on Earth, and a new understanding of how living things adapt to the peculiar conditions of space.

Space Shuttle

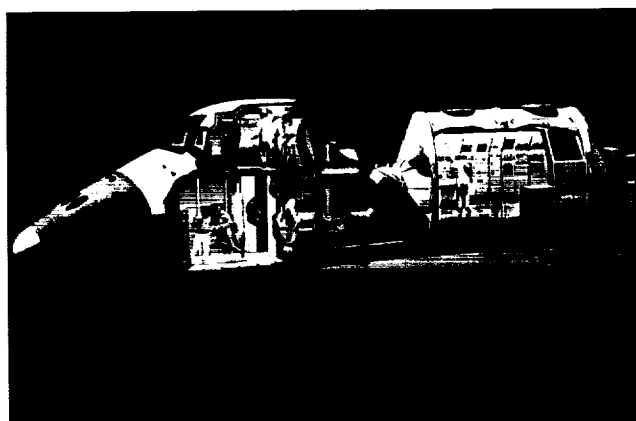
The space shuttle is the principal vehicle for U.S. access to space in the 1980s and early 1990s, and provides many opportunities for life science investigations, from individual tests performed by astronauts to self-contained experiments placed inside storage lockers in the orbiter mid-deck.

Among the LSLE flight hardware items available for use on the shuttle mid-deck are an animal enclosure module for laboratory rodents, a plant growth unit that provides light and temperature controls for plant seedlings, and various recorders and data collection systems.

One new piece of shuttle-related hardware is being developed at the Johnson Space Center in support of the Life Sciences Division's Operational Medicine Program--a compact, lightweight atmospheric analyzer for detecting organic contaminants in the breathing air sealed inside the shuttle or any other spacecraft cabin. The analyzer's ion trap detector has been tested, and its prototype miniature gas chromatograph has been fabricated. The final product will be able to fit in a cupboard-sized shuttle mid-deck locker, whereas commercially available laboratory versions of the same system weigh 350 pounds and occupy 15 cubic feet of volume.



The shuttle Columbia climbs skyward on its second mission, September 12, 1981, and becomes the first human-piloted spacecraft to return to space. Astronauts Joe Engle and Richard Truly crewed the historic flight.



This cut-away view of a typical Spacelab mission shows one possible configuration. The cannister containing the Spacelab hardware is secured in the Shuttle bay. A tunnel with two 90°-bends provides a pressurized link between Spacelab and the Shuttle's mid-deck area. Experiments may be conducted in the mid-deck area as well as in Spacelab itself. The Shuttle's Pilot and Commander monitor its status from the flight deck.

Spacelab

Beginning with its first flight in 1983, the Spacelab has been the primary facility for laboratory science in space. Inside the pressurized laboratory module in the shuttle cargo bay, crews of scientist/astronauts can perform experiments with many of the same amenities found in laboratories on Earth.

Investigations in human, animal and plant biology have been conducted on four Spacelab missions to date. In addition, a total of 39 experiments are manifested for five future Spacelab flights. Two of these--SLS-1 and SLS-2--are dedicated Space Life Sciences missions. Life science investigations will also be included on the International Microgravity Laboratory 1 (IML-1), the Japanese SL-J and the German Spacelab D-2 missions.

In 1987, 29 additional life science investigations were selected for potential flight on future shuttle/Spacelab missions. Twenty-five of the investigations are from U.S. universities, three from NASA field centers, and one--an experiment on cell proliferation and performance in space--is sponsored by the Laboratorium fur Biochemie in Zurich, Switzerland. The experiments represent animal and plant biology studies, as well as virtually all major biomedical disciplines.

The Spacelab facility is a fully equipped laboratory in orbit. Among the specialized LSLE hardware items for use on Spacelab are a rotating chair for vestibular studies, a microcomputer for processing data and a Research Animal Holding Facility--a life support system for rodents and monkeys, which has been upgraded following an engineering test flight on Spacelab 3 in April 1985.

Construction of a General Purpose Work Station for the Spacelab has recently been completed. This facility, to be installed in one of the lab's wall-mounted racks, serves as a laboratory glove box for working with live specimens or common lab chemicals such as formaldehyde and ethanol. Air flow within the work station contains gases and particulates so as not to contaminate the Spacelab atmosphere, while the crew works through glove ports in a small window at the front of the station.

Another new link in Spacelab operations has been established on the ground--a payload receiving facility at the Dryden Flight Research

Center in California. A similar facility for handling delicate biological specimens such as tissues and lab animals immediately after the shuttle lands had already been in place at the Kennedy Space Center in Florida. Since the shuttle's primary landing site will be in California when flights resume, trailers at Dryden's Buckhorn tracking facility were modified to serve as a receiving laboratory. Work stations, chemical hoods, sinks, refrigerators, incubators and other basic life science laboratory equipment will allow for animal maintenance and immediate postflight analysis of flight specimens that are vital to life science research in space.

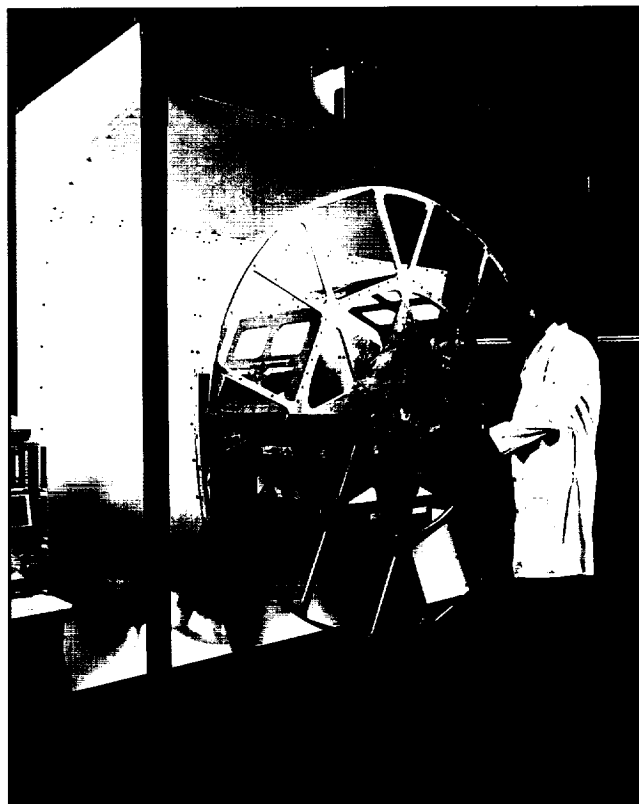
In cooperation with the French space agency, CNES, life scientists at NASA are also studying design requirements for a large primate facility that could allow rhesus monkeys to fly on either the Spacelab or the Space Station. Rhesus monkeys are physiologically more similar to humans than are the smaller squirrel monkeys currently used in flight experiments, and so would be better subjects for researchers to use in extrapolating the effects of microgravity on humans.

Space Station

The existence of a permanent research facility in Earth orbit will allow an entirely different class of life science research in space. Extended duration plant and animal studies will be possible, as well as evaluation of biomedical problems encountered during long-term exposure to the spaceflight environment.

The Flight Programs Branch is now working on preliminary definition studies of a Life Sciences Research Facility to be included on Space Station. A "strawman" list of payloads for the Life Sciences Research Facility has been completed. This reference set of science objectives, experiments and hardware requirements for life science research on the Station serves as a guide for working groups within the Life Sciences division as they conduct advanced planning studies.

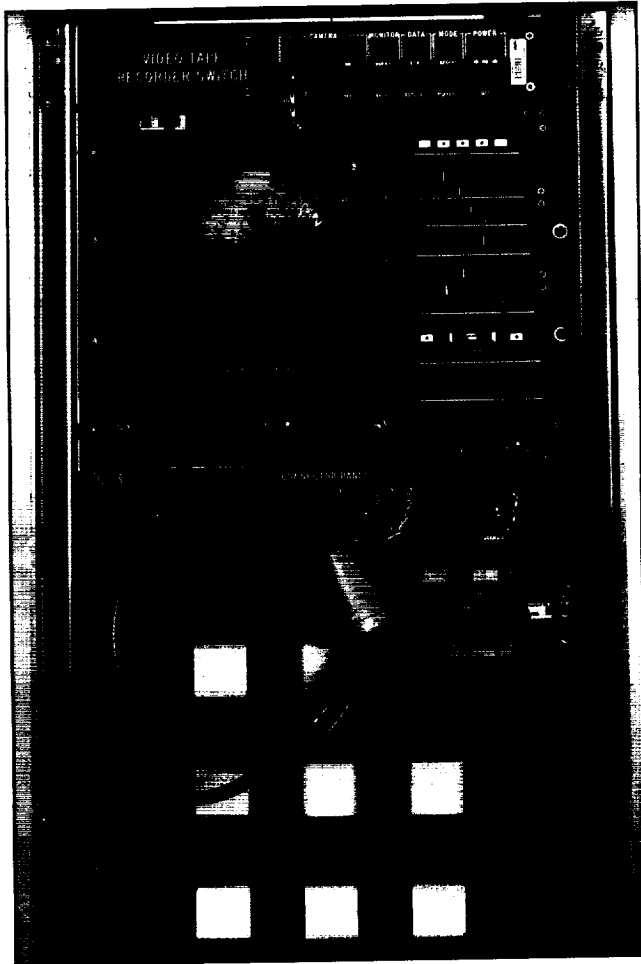
A mockup for a large, 1.8-meter centrifuge to be included on the Station has already been constructed. Current work focuses on the engineering of the centrifuge, which would allow variable gravity studies of plants and



Among the research tools planned for Space Station is the centrifuge. This skeleton prototype of the envisioned 1.8-meter diameter centrifuge is being prepared for engineering tests. The revolving centrifuge will permit small-scale variable-gravity studies on plants and small animals.

small animals. New technology is being studied for potential use in Space Station hardware. For example, air bearings are used in the centrifuge mockup so that its motion causes even less disturbance than the space shuttle's small ventilator fans. Researchers at the Ames Research Center are also investigating the use of robotics to install and remove cages and service other life sciences equipment to minimize the demands on crew time.

Among the possible future payloads for the Station are a larger, 4-meter centrifuge that may allow short-duration human gravitational studies onboard the Station; a cosmic dust collector for exobiology investigations; and a gas-grain simulator that would allow life scientists and others to study small suspended dust and gas particles in weightlessness, and to model the distribution and behavior of organic material in the early solar nebula.



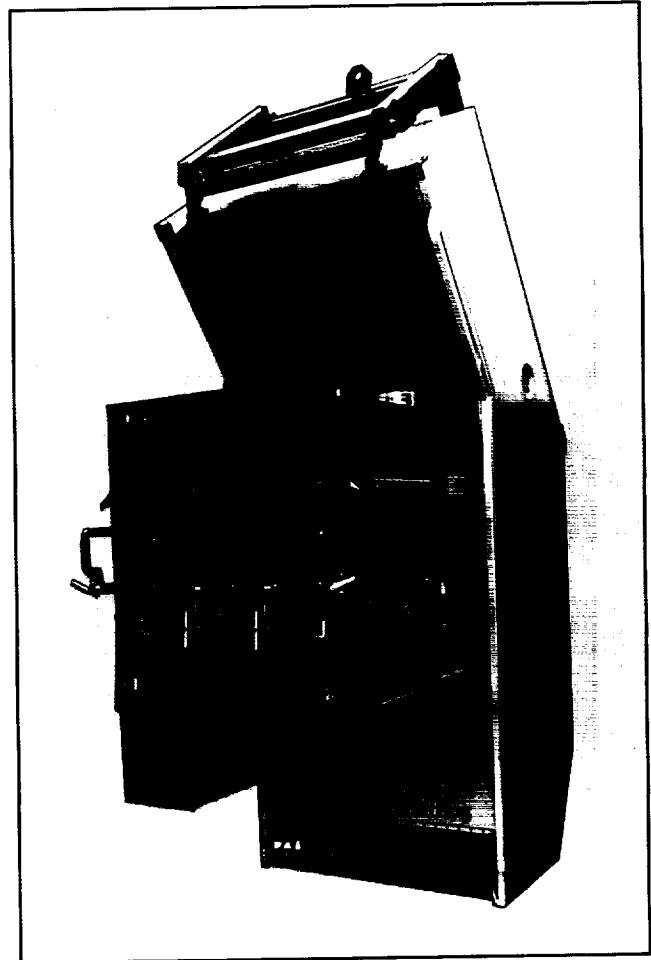
The flight-certified echocardiograph has been used for cardiovascular investigations on several shuttle flights. It displays real time images of the beating human heart using non-invasive ultrasound technology.

Flight Programs - LSLE Life Sciences Laboratory Equipment

The LSLE inventory of flight hardware is made available by NASA's Life Sciences division to experimenters to reduce costs for new equipment used in space. The inventory includes more than 40 items such as data recorders, microscopes, centrifuges and minicomputers, all of which have been flight qualified, and all of which can be used for many different investigations. After each flight, LSLE items are recovered, recertified and returned to storage so that they can be used on future flights.

LSLE Items (Typical)

Animal Enclosure Module
Battery Powered Temperature Recorder



The general purpose work station (GPWS), one of the largest items of Life Sciences laboratory equipment (LSLE), is scheduled to be incorporated into several up-coming Spacelab missions. As work bench, glove box, and "ventilation hood", the GPWS will permit experimentation and materials handling within a secure enclosure.

Bicycle Ergometer
Biological Specimen Test Apparatus
Biotelemetry System
Body Mass Measurement Device
Cassette Data Tape Recorder
Compound Microscope
Dissecting Microscope
Dynamic Environment Measuring System
Echocardiograph
Electrode Impedance Meter
Electromyogram Signal Conditioner
Event Timer
Gas Analyzer Mass Spectrometer
General Purpose Work Station
Liquid Nitrogen Passive Freezer
Hematocrit Centrifuge
Lower Body Negative Pressure Device
Low Gravity Centrifuge Microcomputer
Middeck Rotator Device
Mini-oscilloscope
Mini-spectrophotometer
Multichannel Strip Chart Recorder

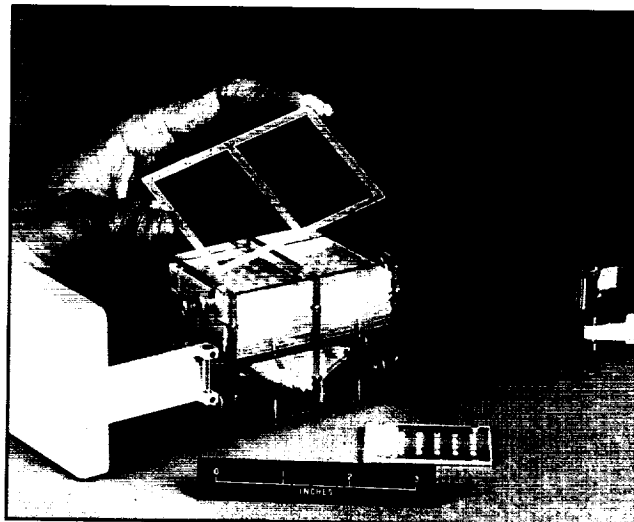
Orbiter Centrifuge
 Physiological Monitoring System
 Plant Growth Unit
 Pocket Voice Recorder
 Rack Mounted Centrifuge
 Refrigerator/Freezer
 Refrigerator Incubator Module
 Research Animal Holding Facility
 SL-1 Inflight Blood Collection System
 SL-2 Inflight Blood Collection System
 Small Mass Measurement Instrument
 Stowage Container (001)
 Stowage Container (002)
 Ultrasound Limb Plethysmograph
 Urine Monitoring System
 Venous Occlusion Cuff

In addition, two new LSLE items were added this year: an Automatic Blood Pressure System for monitoring blood pressure non-invasively during exercise; and a System for Venous Occlusion Plethysmography, a battery-powered device that, when applied to the arm or leg, derives information on blood flow and limb vein pressure and volume.

Flight Programs Missions The Spacelab Program

The primary payload for Space Life Sciences-1 (SLS-1), the first Spacelab mission dedicated entirely to life sciences research, consists of seven complete studies and three partial investigations. These studies form a comprehensive, interrelated, and scientifically balanced inquiry into pressing biomedical issues of space flight: cardiovascular deconditioning, space motion sickness, metabolic changes, muscle atrophy and bone demineralization. The second dedicated Spacelab mission for life sciences research, SLS-2, consists of studies and investigations in the same areas as SLS-1 with the addition of a thermoregulation experiment.

The international missions consist of investigations from nearly 200 scientists in the United States and 12 other countries. The International Microgravity Laboratory One (IML-1) mission, sponsored by the U.S., Japan, and the member nations of ESA, focuses on life sciences and materials experiments. The Japanese Spacelab (SL-J) mission is jointly sponsored by NASA and the National Space Development Agency of Japan (NASDA). Approximately 38 investigations in microgravity sciences and life sciences will be conducted on



The Biorack experiments will study the effects of radiation in space and microgravity with biological dosimeters. Yeast cells or minute nematode roundworms are sandwiched between metal foil, used as radiation path detectors, then stacked in layers into the container. The passive experiment package flies on a mission and is analyzed upon the Shuttle's return. Later studies will examine microgravity effects on other biological materials.

SL-J. The D-2 (Deutsche-2) Spacelab mission is the second in a series in conjunction with the German Space Agency. Payload development and negotiations for D-2 are underway.

SLS-1/SLS-2 Investigations

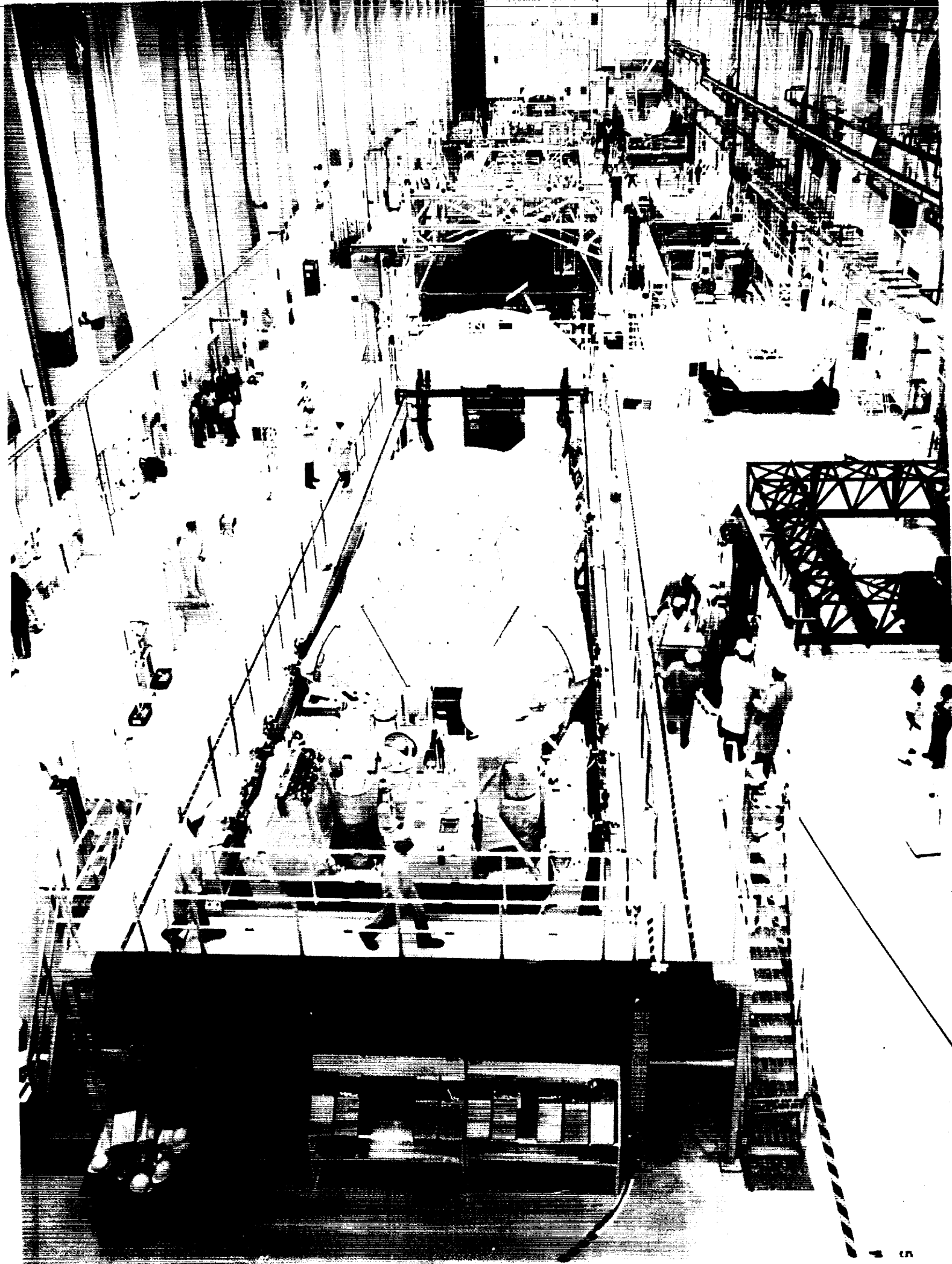
Cardiovascular adaptation to microgravity/readaptation to Earth gravity
 Vestibular adaptation and function in microgravity
 Microgravity effects on fluid-electrolyte regulation systems
 Documentation of blood volume and red cell mass losses
 Effects of human lymphocyte activation and cellular alterations on human immune responses during spaceflight
 Role of nitrogen in muscle atrophy during spaceflight
 Microgravity effects on calcium homeostasis and bone metabolism
 Microgravity effects on animal development, behavior and over-all morphology
 Impact of thermoregulatory factors on circadian rhythm during spaceflight

IML-1 NASA-sponsored Investigations

Effects of microgravity and cosmic radiation on plants, cells, bacteria, and nematodes (roundworms)
 Plant response to light in microgravity and to induced gravity
 Human vestibular investigations conducted in microgravity
 Studies of human workload and performance during spaceflight

SL-J NASA-sponsored Investigations

Embryo development of frog eggs in microgravity
 Muscle strength and fatigue in the microgravity environment



International Cooperation

Space research in the 1980s has become a highly international enterprise, involving not only the major spacefaring powers but also many other nations who sponsor experiments, satellites and payload specialists aboard our space shuttle and who contribute significantly to specific space research objectives. Virtually every space shuttle launch is to some degree an international cooperative venture, with a non-U.S. satellite or investigation onboard. It is to the benefit of the entire world that the different nations unite in an endeavor that takes us to the root of man's existence on this planet-exploration of the unknown.

The value of developing strong and healthy relationships in space research with our many international colleagues can be seen and understood on different levels. The value to our nation comes from the development of an open communication network that transcends the political and social boundaries existing between different nations. This network helps to identify areas of commonality and allows researchers to work together to understand very basic scientific questions, including those about the relationship that exists between living things and our universe.

The Life Sciences Division has developed a vigorous program of international cooperation in order to take full advantage of the limited access to space by consolidating worldwide research talent in the space life sciences into an effective, collaborative community of scientists working together on problems and questions of mutual interest. Only by establishing formal joint working groups with nearly all of the major nations or agencies interested in pursuing space life sciences research will an efficient, internationally-based, coordinated program of flight and supporting ground research emerge which is appropriate for the future space

research era. Such joint working groups provide a forum for direct scientist-to-scientist discussions worldwide, facilitate the development of appropriate space and ground research facilities, significantly extend the economic boundaries by sharing responsibilities for hardware development and other high expense ventures, and provide a management structure suitable for the coordination of future international research projects.

With this in mind, the Life Sciences Division has established formal joint working groups with the European Space Agency (ESA), Japan (through its space agency, NASDA), the Soviet Union, France (CNES), and the Federal Republic of Germany (DFVLR). It is likely that a joint working group will be formed with Canada in the near future. These groups meet once or twice a year to discuss present and future projects of mutual interest, and to exchange information on scientific and management issues of concern.

Included among the many international projects which have been initiated in the last two years are: joint NASA and ESA utilization of the ESA-developed BIORACK and ANTHRORACK facilities on future Spacelab missions; joint NASA and NASDA participation in the Spacelab-J and International Microgravity Laboratory (IML-1) missions; NASA participation in the Soviet COSMOS biosatellite missions; joint NASA and CNES development of a special Rhesus Research Facility for future Spacelab flight; NASA participation in joint research projects on the next West German Spacelab mission, D-2; and joint NASA and CNES neuroscience studies on the IML-1 mission utilizing a NASA-developed rotating chair.

The space life sciences community is relatively small and widely distributed around the world. Therefore, great benefit is derived

Payloads for the Space Shuttle bay are assembled in the Operations and Check-out (O&C) Building at the Kennedy Space Center. Spacelab equipment and experiments are tested, assembled, integrated with the module shell, and tested again before the entire Spacelab unit is readied for placement in the Shuttle's bay. Spacelab and adjunct equipment were built by the member nations of the European Space Agency.



Educational Programs

Our destiny awaits us in the new frontier of space. An era of exploration began anew thirty years ago and it continues today. As we prepare to spend more and more time living and working in that new frontier, the space life sciences become increasingly vital areas of study. Today's youth will be tomorrow's explorers and researchers in space, expanding our knowledge of the universe and ourselves, working for peaceful scientific and economic gain, and reaching for the stars.

NASA encourages the nation's young people to share in the excitement of our adventure as we probe these new realms of knowledge. To help achieve this goal, NASA offers a wide range of educational opportunities relating to its work in space medicine and biology. Programs are directed towards students at all levels of preparation, from secondary school through postdoctoral studies. Some programs are focused specifically on space life sciences, but the majority are relevant to all areas of NASA science and technology endeavors.

The Life Sciences Division funds and administers wholly or in part a number of educational programs which relate directly to life science research in space. Brief descriptions of these programs are provided in this section. Additional detailed information may be obtained by contacting the Life Sciences Division or Educational Affairs Division at NASA Headquarters or the Education Program Officer at the nearest NASA Center.

Space Life Sciences Training Program

College and university students interested in space biomedicine and other life sciences can take advantage of this intensive six-week summer program at the Kennedy Space Center in Florida. Participants prepare actual space shuttle experiments for flight, and earn five semester credit hours while gaining hands-on experience with space-qualified hardware.

In cooperation with a NASA-funded principal investigator, students participate in the design and performance of life sciences experiments suitable for space flight. Previous experiments within the program have explored questions in exercise physiology, aquatic and bacterial ecology, the effects of space on the vestibular system, and nutrient delivery to animals.

The program augments laboratory experience with lectures by astronauts and national and international leaders in life sciences. Students have the opportunity to interact on a personal basis with these lecturers, and with astronauts and other NASA personnel active in ongoing space research.

Applicants must be U.S. citizens, have a GPA of 3.0 or better, and be in their first three years of working toward an undergraduate degree. Thirty students participated in the program in 1986, with 36 more in 1987. One 1986 graduate of the program has already made her professional mark in the space sciences: MIT student Jennifer Wiseman, of Mountain Home, Arkansas, who discovered a comet in January 1987 while working on a cooperative study program at the Lowell Observatory in Flagstaff, Arizona.

Arabella, one of the two Skylab 3 common cross spiders, sits in the middle of a web it had spun in microgravity. Submitted by high school student Judith Miles (then 17 years old), the spider experiment was one of 25 selected from over 3400 experiment proposals by high school students throughout the nation.

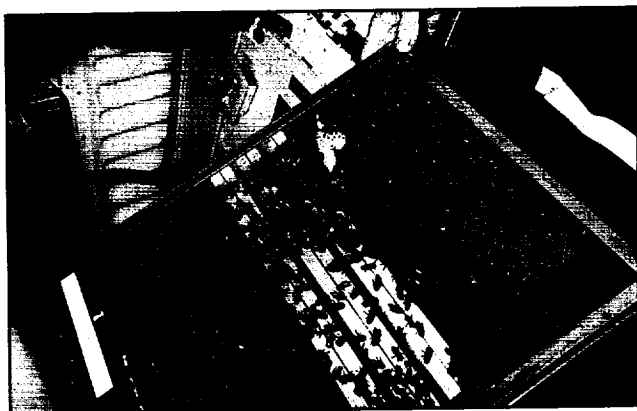


Astronaut James van Hoften, 41-C mission specialist, holds an aluminum box full of honey bees. Dan Poskevich submitted the experiment proposal to NASA as part of the Shuttle Student Involvement Program.

Space Science Student Involvement Program

The Space Science Student Involvement Program familiarizes secondary school students with unique aspects of scientific research in relation to the Space Shuttle. Each student prepares a proposal for an experiment, demonstration, or set of activities to be performed by a member of the flight crew. Each proposal should utilize one or more of the Space Shuttle's unique features (e.g., the low-gravity environment).

Entries are evaluated according to their scientific validity, suitability, creativity, originality, organization, and clarity. NASA and their selected sponsors provide assistance to winners in developing their projects, analyzing



Close-up view of the young colony of 3000 bees which spent seven days onboard STS Mission 41-C building their honeycomb hive. As a comparison for the space bee colony, a similar colony was monitored on earth during the same period by then high school senior and experiment proposer Dan Poskevich.

the resulting data, and reporting their findings. The Space Science Student Involvement Program is traditionally renewed at the start of each school year; winners are selected the following spring.

Graduate Student Researcher Program

Opportunities are provided for 40 graduate students in aerospace science and technology to conduct thesis research at a participating NASA center. The program offers 40 additional awards for students to conduct NASA-related research at their home institutions. Applicants must be currently enrolled in an accredited college or university and must be U. S. citizens. Students may enter the program at any time during their graduate degree work or may apply prior to receiving their baccalaureate degree. Selections are made for a 1-year period and may be renewed annually for no more than 3 years.

Aerospace Medicine Resident Program

The Civilian Residency Program in Aerospace Medicine is a two-year residency that involves participation in medical operations activities and ongoing research in aerospace physiology and medicine at Wright State University School of Medicine in Dayton, Ohio. Research is carried out in conjunction with the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base. The curriculum includes participation in both Medical Operations activities and ongoing research in aerospace physiology and medicine. The residency is followed by a third-year rotation at a NASA research center.

Space Biology Research Associate Program

The Space Biology Research Associate Program is available to scientists in the field of space biology who have Ph.D., D.Sc., M.D., D.D.S. or D.V.M. degrees. Program applicants must be U.S. citizens. Specific independent projects of the individual awardees' design are conducted at university laboratories or facilities of their choice. Proposals are evaluated on scientific merit, and awards are made in January and June for one-year periods, with annual renewals possible.

Resident Research Associate Program

Several training opportunities have been established for researchers at the graduate and postgraduate level. The Resident Research Associate program (RRA) is a postdoctoral program conducted by NASA and the National Research Council. Outstanding scientists and engineers from the United States and foreign countries participate in national competition for grant awards which permit them to work as guest investigators at NASA's Ames Research Center, Jet Propulsion Laboratory or Johnson Space Center. Selections are made from applicants who choose a research problem compatible with research goals at the sponsoring laboratories. Awards are for a one-year period. They may be renewed, and are designated as either Regular Research Associateships (for those who have held a doctorate for less than five years) or Senior Research Associateships (more than five years).

Planetary Biology and Microbiology Ecology Research Program

This research program is designed to provide participants with theory and practice in assessing the impact of microbes on the Earth. It is an intensive six-week summer program, offered every other year, and held jointly at NASA Ames Research Center and San Jose State University. Advanced graduate students and postdoctoral fellows with a background in microbiology, atmospheric sciences, geology, or geochemistry are eligible to apply.

Planetary Biology Intern Program

Graduate students in selected fields related to planetary biology have the opportunity to participate in an intern program conducted at various universities and NASA research centers. Interns participate in research activities during eight-week summer terms, under the direction of a NASA-sponsored investigator. Graduate students and senior undergraduates majoring in biology, paleontology, atmospheric sciences and geochemistry are eligible to apply.



Appendix 1

Additional Reading

The following documents provide additional details about many of the programs and accomplishments summarized in this report. The listing is not intended to be exhaustive, but rather to identify key references.

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Appendix 2

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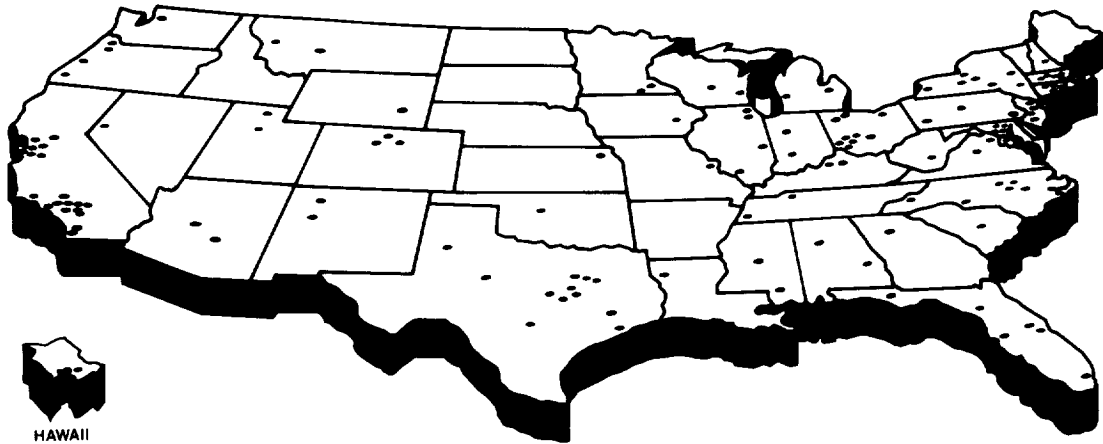
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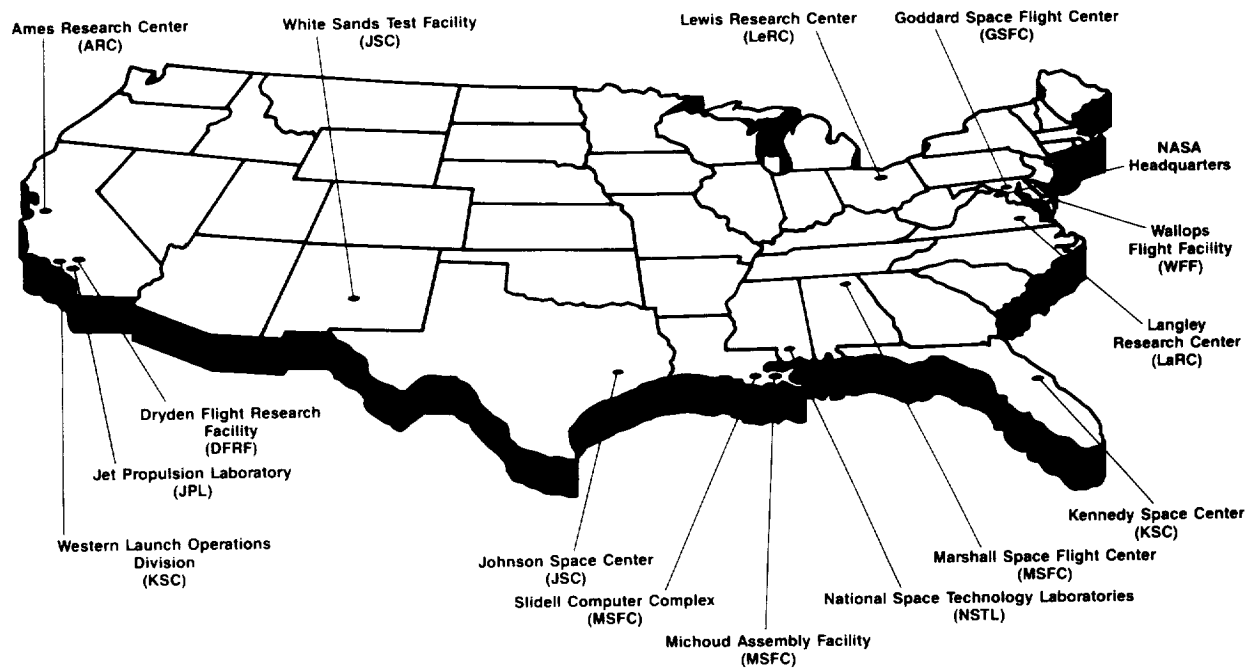
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**ACADEMIC INSTITUTIONS, GOVERNMENT (NON-NASA) ORGANIZATIONS AND
COMMERCIAL FIRMS ENGAGED IN LIFE SCIENCES RESEARCH**



Life Sciences Research in the United States

NASA MAJOR AND COMPONENT INSTALLATIONS



NASA Major and Component Installations

Appendix 5

Life Sciences Research in the United States

This listing includes some U.S. government organizations, academic and research institutions, and commercial/industrial firms conducting NASA life sciences research. Refer to map for geographical locations.

ALABAMA

University of Alabama
Tuskegee Institute

ARIZONA

Arizona State University
University of Arizona

CALIFORNIA

Veteran's Administration Medical Center
University of California - branches at
Berkeley
Davis
Irvine
La Jolla
Los Angeles
Northridge
Riverside
San Francisco
Santa Barbara
Linus Pauling Institute
University of Southern California School of Medicine
Molecular Research Institute
California Institute of Technology
California State University
University of California Medical Center
San Diego State University
Salk Institute for Biological Studies
University of the Pacific
University of San Francisco
San Francisco State University
San Jose State University
University of Santa Clara
Stanford University
Joint Sciences Center
Rockwell International
SRI International
Medical Corporation

COLORADO

University of Colorado - branches at
Boulder
Denver
Colorado State University

CONNECTICUT

Naval Submarine Medical Research Laboratory
Yale University
Springborn Laboratories
Hamilton Standard

DELAWARE

College of Marine Studies

DISTRICT OF COLUMBIA

Armed Forces Institute of Pathology
Library of Congress
Georgetown University
George Washington University
Howard University
Aerospace Medical Association
American Institute of Biological Sciences (AIBS)

FLORIDA

Veterans Administration Medical Center
University of Miami
University of Florida
University of South Florida
Florida State University
Florida A&M University
Bionetics Corporation
Essex Corporation

GEORGIA

Emory University
Georgia Institute of Technology

HAWAII

University of Hawaii, Manoa

ILLINOIS

Argonne National Laboratory
Southern Illinois University
University of Chicago
University of Illinois at Chicago
Rush Medical College
Northwestern University
University of Illinois-Urbana

INDIANA

Indiana University
Purdue University

IOWA

University of Iowa

KANSAS

Kansas State University

KENTUCKY

University of Kentucky
University of Louisville

LOUISIANA

Tulane University
Louisiana State University

MARYLAND

Federation of American Societies for
Experimental Biology (FASEB)
Johns Hopkins University
University of Maryland - branches at
Baltimore
College Park
Martin-Marietta Labs
Beltsville Human Nutrition Research Center
National Center on Radiation Protection
Universities Space Research Association
Exotech Research and Analysis

MASSACHUSETTS

Amherst College
University of Massachusetts
Boston University
Bridgewater State College
Harvard University
Massachusetts Institute of Technology
Tufts University
Harvard Medical School
Baystate Medical School
Brandeis University
Woods Hole Oceanographic Institution
Modar, Inc.

MICHIGAN

University of Michigan
Hope College

MINNESOTA

Mayo Clinic

MISSISSIPPI

University of Mississippi
National Space Technology Labs

MISSOURI

Washington University
St. Louis University

MONTANA

Montana State University

NEVADA

University of Nevada

NEW HAMPSHIRE

University of New Hampshire

NEW JERSEY

University of Medicine & Dentistry of
New Jersey
Fairleigh Dickinson University
Columbia Scientific, Inc.
Medical Association, Inc.

NEW MEXICO

University of New Mexico
Los Alamos Scientific Laboratory
Lovelace Medical Foundation

NEW YORK

State University of New York - branches at
Albany
Binghamton
Brooklyn
Buffalo
Stony Brook
Brooklyn College
Veteran's Administration Medical Center
Polytechnic Institute of New York
Cornell University
Rockefeller University
Mt. Sinai School of Medicine
Columbia University
New York University Medical Center
Beth Israel Medical Center
State University Hospital
Rensselaer Polytechnic Institute
Brookhaven National Laboratory

NORTH CAROLINA

University of North Carolina
Western Carolina University
Duke University
North Carolina State University
Wake Forest University

OHIO

Wright Patterson Air Force Base
Bowling Green State University
University of Cincinnati
Case Western Reserve University
Ohio State University
Wright State University
Miami University
University of Toledo
Clinical Radiology Testing Laboratory

OKLAHOMA

University of Oklahoma

OREGON

Oregon Graduate Center
University of Oregon
Good Samaritan Hospital

PENNSYLVANIA

University of Pennsylvania
Thomas Jefferson University
Drexel University
Hahnemann University
Temple University
University of City Science Center
University of Pittsburgh
Pennsylvania State University

SOUTH CAROLINA

University of South Carolina

TENNESSEE

University of Tennessee
Vanderbilt University

TEXAS

U.S. Air Force School of Aerospace Medicine
Hardin-Simmons University
Texas College of Osteopathic Medicine
Southwestern Medical School
University of Houston
Baylor College of Medicine
Texas Medical Center

Texas Research Institute of Mental Science
Texas Technological University
University of Texas - branches at
San Antonio
Houston
Galveston
Austin
Dallas
Baylor University
Phyto Resource Research, Inc.
Spectrix Corporation
Technology, Inc.
Austin & Associates Clinical Psychology

UTAH

Utah State University
University of Utah

VIRGINIA

Virginia Polytechnic Institute
University of Virginia
Eastern Virginia Medical School
Virginia Commonwealth University
Veteran's Administration Medical Center
Advanced Technology, Inc.

WASHINGTON

University of Washington
Veteran's Administration Medical Center

WEST VIRGINIA

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